ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA

JOURNAL

PP 21/8/92

No.2


We can focus
our skills
on your issues

ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA

Journal

July 1993

CONTENTS

Publisher
- *THE ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA*
  Unit A 2-22, Block A, 2nd Floor
  P.J. Industrial Park, Jalan Kemajuan
  Section 13, 46200 Petaling Jaya
  Selangor, Malaysia
  Tel: 03-7571159
  Fax: 03-7575011

Printer
- *Percetakan Bahagia*
  3 Jln. Jejaka Dua, Tmn. Maluri
  Kuala Lumpur

Lay-Out
- *AC Designers Sdn Bhd*

COVER: Spiral ramps on Metropolitan Expressway, Japan.

DEVELOPMENT OF PRIVATISATION OF TOLL HIGHWAYS IN MALAYSIA

by

CHEW SWEE HOCK
Director General
Malaysian Highway Authority

SYNOPSIS:

The Malaysian experience in financing highway projects through privatisation is described. The concept of privatisation, brief information on current projects and features of Built-Operate-Transfer contract are presented.

1. Malaysian Road Development In Brief

Prior to the independence of Malaya in 1957, roads were built primarily for the purpose of trade, i.e. to provide transportation between the production areas (mainly rubber estates and tin mines) and the ports, and also to serve urban and business centres. While the west coast of Malaya (peninsula) saw some sporadic road development during the early part of the century, the east coast achieved very little development. There was not even one single continuous road link in the east coast. During the same period, the road networks in Sabah and Sarawak (East Malaysia) were even less developed. Prior to the formation of Malaysia (Union of Malaya, Sabah, Sarawak and Singapore, the latter seceded in 1965) in 1963, the First Malaya Plan (1956-1960) and Second Malaya Plan (1961-1965) did put in some effort to link up the lesser populated towns and villages with the national road network. More comprehensive planning for roads occurred only after the formation of Malaysia. During the First Malaysia Plan (1966-1970) the General Transportation Study (1967) laid the groundwork for consistent policies in road development. The Second Malaysia Plan (1971-1975) placed emphasis on the development of road in regional land schemes and their links to the national network, while the Third Malaysia Plan (1976-1980) had its thrust in developing rural roads to provide high standard access to under-developed hinterland. These were the times when Malaysia's economy was highly dependent on the primary commodities. In the eighties, Malaysia began to move towards industrialisation. The need to upgrade the road system to facilitate more efficient movement of people and goods became more urgent. The Fourth (1981-1985), Fifth (1986-1990) and now the Sixth Malaysia Plans have all steered road development in this direction. Inter-urban highway development is a major aspect of these plans.

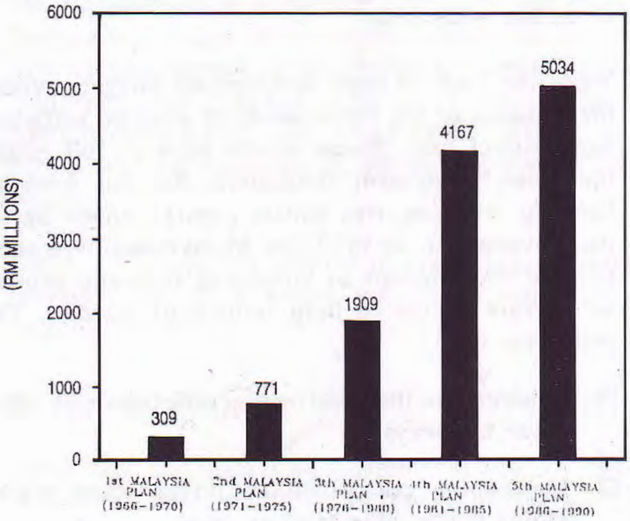


Fig. 1: Five-year Development Plan Road Expenditure

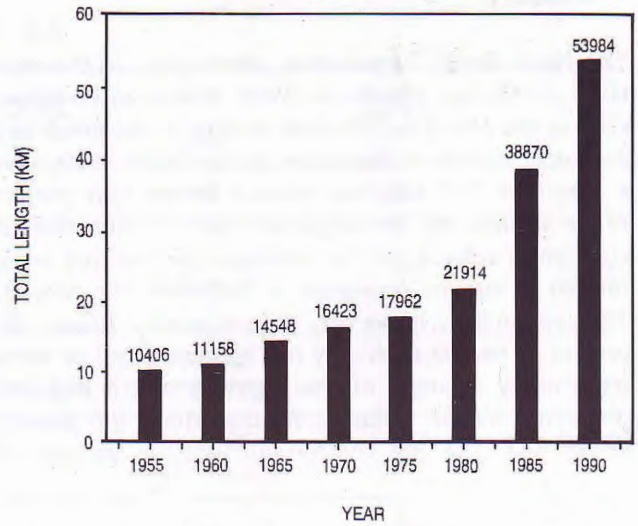


Fig. 2: Total Road Length In Malaysia (Km)

Fig. 1 shows the allocations and expenditures on roads for the various Malaysia Plans, while Fig. 2 shows the growth of road network in terms of total length.

(This paper was presented at PIARC Yokohama Meeting on 27 April 1993)

2. Road Project Financing

Road development, being one of the functions of government, is traditionally financed through national revenue or through borrowing from external sources such as the World Bank or the Asian Development Bank. The concept of financing through direct user charge, i.e. toll, however, is not new in Malaysia. The first toll highway, the Slim River/Tanjong Malim Highway, 20 km in length, was opened to traffic in 1966. At around the same period, several bridges (such as the Muar Bridge, Pekan Bridge, and Sultan Yahya Petra Bridge) were also financed through toll. But tolling at that time was restricted to specific projects on ad hoc basis only.

When the level of road development budget exceeds the capacity of the Government to allocate sufficient fund, direct user charge in the form of toll is the immediately apparent alternative. But this mode of funding still requires initial capital financing by the Government. In 1977, the Malaysian Government mooted the concept of financing highway project by private sector to help reduce its burden. The objectives were:

- ☐ to accelerate the construction programme of inter-urban highways,
- ☐ to encourage participation of private sector in providing public infrastructure, and
- ☐ to utilise fully the capacity of the construction industry.

The North-South Expressway, which runs on the west coast of Malaya Peninsula (West Malaysia) commencing at the Malaysia/Thailand border in the north and ending at Malaysia/Singapore border in the south over a length of 782 km, was chosen as the first project to be funded on privatisation basis. Consortia of companies related to road construction industry were invited to submit proposals to undertake the project. The consortia, however, subsequently found the project to be commercially not viable overall as there were many sections of the highway which had low projected traffic volume. At that time, the private sector was also not comfortable with investment in long term ventures.

In view of this situation, the Government set up the Malaysian Highway Authority in 1980 to develop the North-South Expressway as well as all other proposed toll highways. The Authority is a statutory body set up under a parliamentary act which empowers it to design, construct, operate and maintain designated highways. To finance its projects, the Authority receives grants from the Government and at the same time borrows from local and foreign financial institutions to supplement its budget. Toll is its main source of revenue.

The main project of the Authority at its inception was the proposed North-South Expressway. Physical construction of the expressway commenced in 1985. Just prior to this, the Government, being very concerned with the heavy burden of infrastructure development, revived the concept of privatisation. This led to the privatisation of some highway projects, the biggest one being the North-South Expressway, which at the time of being privatised (in 1988) was already partially completed. (Further details of these projects are elaborated later in this paper.) The decade of the eighties has seen the beginning of Malaysia embarking on highway privatisation earnestly.

3. Privatisation Policy

Privatisation was formally adopted by the Malaysian Government as a national policy in mid 1983. The aim is to stimulate the growth of the private sector and to improve overall efficiency in the economy. The underlying philosophy is that the private sector, being motivated by profit maximisation, is able to promote efficiency and productivity better than the public sector. By definition, privatisation refers to the transfer from public to private sector certain traditional activities and functions of certain Government agencies. Generally, such transfer would involve assets, management responsibility and personnel. In 1987, the Government commissioned consultants to prepare a master plan called the PRIVATISATION MASTER PLAN, in which the objectives are stated as:

- ☐ to relieve the financial and administrative burden of the Government in undertaking and maintaining a vast and constantly expanding network of services and investment in infrastructure,
- ☐ to promote competition, improve efficiency and productivity,
- ☐ to facilitate economic growth,
- ☐ to reduce the size and presence of the public sector in the economy, and
- ☐ to help meet the national development policy targets.

Four main methods of privatisation have been identified, namely, through (a) **sale of assets or equity**, (b) **lease of assets**, (c) **management contract**, and (d) **build-operate** or **build-operate-transfer**. Privatisation can be applied to enterprises already owned by the Government or to new projects planned by the Government. Highway privatisation generally falls under the latter category. In the following parts of this paper, various aspects of highway privatisation in Malaysia will be presented and discussed.

4. Role of Government Agency, Engineer & Contractor — Historical Development

From the early days of road development in Malaysia right up to the sixties, road infrastructure implementation had always been entirely undertaken by Government agencies (Public Works Department and various local authorities), from planning, survey, design, construction, operation to maintenance. Fund for infrastructure was allocated by the Government. In the early seventies, private contractors began to emerge to undertake construction works. Then in the later part of the seventies, the big number of road infrastructure projects created under the Third Malaysia Plan (1976-1980) gave a tremendous impetus to the growth of engineering consultancy industry as the Government agencies alone could not cope with the work load. Private consulting engineers were engaged to assist the public sector in the design and supervision of construction works done by contractors. The practice of employing contractor to carry out maintenance works began to develop around the early eighties. Until this time, the **"CONVENTIONAL"** concept of

CLIENT (Government) <——> ENGINEER (Consultant) <——> CONTRACTOR

had been very well developed and practised. Then in the early eighties, the concept of **"TURNKEY"** was introduced to the country. Basically, this concept combines the roles of the Engineer and the Contractor into one entity, generally known as the TURNKEY OPERATOR, whose function covers design and construction. The relationship became

CLIENT <——> TURNKEY OPERATOR

But whether it is conventional or turnkey concept, the financing, operation and maintenance of the project always remain the responsibility of the Government. Then soon after the advent of the turn- key concept, the privatisation concept was adopted. In a privatised highway project, the traditional activities of design, construction, operation, main- tenance and financing are transferred to a private company, while the Government retains the planning function and control over certain aspects of the highway administration. Generally, the process consists of the stages of **BUILD, OPERATE** and **TRANSFER (BOT)**. The details will be discussed in subsequent part of this paper.

Table 2.2 should be helpful in clarifying the roles played by the Government and private company in each of the concept.

5. Current Projects

Up to date, the Malaysian Government has privatised two rural and two urban highway projects. The followings are brief description of each of the projects.

TABLE 2.2

ACTIVITY	CONVENTIONAL Before 1970	CONVENTIONAL 70's – 80's	CONVENTIONAL 90's	TURNKEY	B.O.T
Planning	**GA**	**GA**	**GA**	**GA**	**GA**
Design	mainly **GA**	mainly **GA** role of **CE** growing	mainly **CE**	**TO**	**CONC**
Construction	mainly **GA**	mainly **CONTRACTOR**	practically all by **CONTRACTOR**	**TO**	**CONC**
Work supervision	**GA**	**GA/CE**	mainly **CE** approx. equally	**TO**	**CONC**
Operation	**GA**	**GA**	**GA**	**GA**	**CONC**
Maintenance	**GA**	mainly **GA**	mainly **GA** with growing role of **CONTRACTOR**	**GA** (through contractor)	**CONC**
Project financing	**GOVT.**	**GOVT.**	**GOVT.**	**GOVT.**	**CONC**
Toll collection	**GA**	**GA**	**GA**	**GA**	**CONC**

Abbreviation:
GA: Government Agency
CONC: BOT Concession company
GOVT.: Government
CE: Consulting Engineer
TO: Turnkey Operator

The North Klang Straits Bypass (NKSB)

Port Klang, the largest port of Malaysia, is situated about 40 km west of Kuala Lumpur. The highway that links Kuala Lumpur to the port passes through Klang, a city with congested roads situated about 5 km east of Port Klang. To facilitate free flow of traffic between Port Klang and Kuala Lumpur, a road bypassing Klang, 15.3 km in length, had been built, commencing from the eastern side of Klang, skirting the town on the north side and connects the northern part of Port Klang. See Fig. 3. This road, being founded on soft coastal alluvium, requires heavy maintenance because of frequent subsidence. Inadequate maintenance allocation had left the road in very poor condition. In 1983, a private company submitted a proposal to take over the road for a period of 20 years, with undertakings to rehabilitate the road to a specified standard of service condition, operate and maintain the facilities. In exchange, the company asked from the Government the concession to collect and retain tolls (fixed at $ 0.50 for passenger car and $1.00 for commercial vehicle, motorcycles and bus being exempted, over the concession period). At the end of the concession period, the facilities will be transferred back to the Government. After the Government accepted the proposal, rehabilitation works began in April 1984 and was completed in December the same year at a cost of RM 14.5 million. This tolled bypass has been in operation satisfactorily since then.

Kepong Interchange and Kuching Road, Kuala Lumpur

Kuching Road is an arterial which leads northwards radially from the centre of Kuala Lumpur. It meets Kepong Road and Ipoh Road at an intersection. Traffic through this intersection was previously handled by only a roundabout. By the late seventies, the capacity of the roundabout and the connecting roads could no longer handle the high volume of traffic, both between the city centre and the north, and between the city centre and the Kepong urban centre on the northwest. Road authority had planned to build a three level grade-separated interchange consisting of a roundabout at the ground level, a second level flyover to the north and a third level flyover for city bound traffic from Kepong. See Fig. 4. At the same time, about 5.3 km of Kuching road from the roundabout to the city centre would be up- graded from dual two lane to dual three lane. Owing to lack of fund, however, the project could not be implemented. Then in 1984, the Government decided to implement it through privatisation on build-operate-transfer basis. Tenders were invited from suitably qualified local companies. Tenders were evaluated on the adequacy of design (based on a preliminary engineering design), period of toll collection, and technical and financial capacities of the tenderer. Toll rates had been fixed over the toll period by the Government at RM 0.50 per direction for passenger car, RM 1.00 for commercial vehicle, with exemption for motorcycle. The contract was awarded in November 1984, with a concession period of 16 years. Survey, design and construction took about two years. The upgraded facilities were completed in early 1987. Since then the project has been performing satisfactorily.

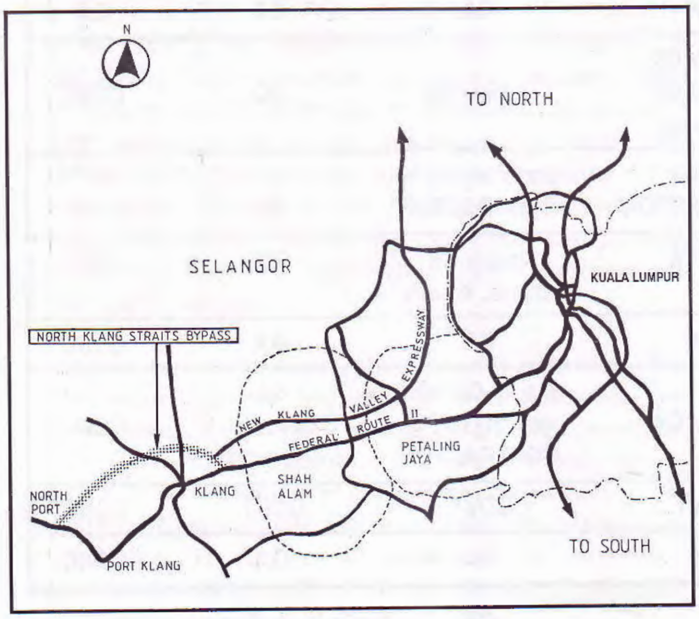


Fig. 3: North Klang Straits Bypass

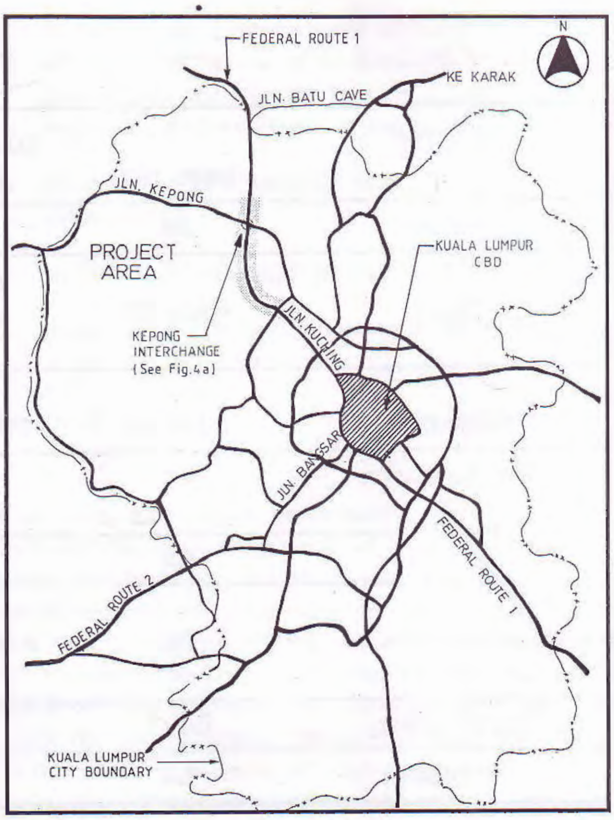


Fig. 4: Kepong Interchange and Upgrading of Kuching Road, Kuala Lumpur

■ The North-South Expressway

The North-South Expressway is the single biggest highway project ever implemented in Malaysia up to date. It commences at Bukit Kayu Hitam at the border between Malaysia and Thailand, traverses southwards on the Malay Peninsula through the states of Kedah, Penang, Perak, Selangor, the Kuala Lumpur Federal Territory, Negri Sembilan, Malacca, Johore and ends at the causeway at the border with Singapore. This project, a fully access-controlled expressway 782 km in length, was identified and planned by the Highway Planning Unit to be the spine of the road network on the west coast of the peninsula. See Fig. 5. To implement this project, the Malaysian Government in 1980 set up the Malaysian Highway Authority, a statutory body empowered to raise loans for the project. The Authority commenced physical construction in 1985, and by 1987 sections of the expressway totalling 324 km had been completed. Then, in 1986, the Government decided to privatise the whole project in order to reduce its financial burden of infrastructure development. Proposals were invited on competitive bidding basis from companies or consortia of companies to under- take the remaining sections of the expressway (totalling 458 km) on build-operate-transfer basis. The sections of expressway which were already built by the Malaysian Highway Authority were offered at the same time to the bidders on transfer-operate-transfer basis. After evaluation and selection, the concession was awarded to a company in 1988. Physical works commenced in early 1989. The whole Expressway is scheduled to be completed in early 1994, with completed sections open to traffic in stages. Presently, works are in full swing while many completed sections are already in operation.

■ Upgrading of Cheras Road, Pahang Road and Certain Intersections in Knala Lumpur City

This project comprises the upgrading of two highly congested roads and four bottleneck intersections in the Federal capital. See Fig. 6. Tolls are to be imposed at the roads, so that the revenue derived will cross subsidise the construction of interchanges at the intersections. After competitive bidding on build-operate-transfer basis, a concession agreement was entered into between the Kuala Lumpur City Hall and a private company in 1987 for a concession period of 12 years. Initially, this project met with very strong protest from the local residents on the ground that toll was imposed on existing, though upgraded, roads which had no alternative toll-free roads. After modifications were made to the agreement, the project is now partially completed, with toll collection at Cheras Road in operation.

6. Features of BOT concession agreement

BOT concession agreement contains several features which defer from the conventional contract as

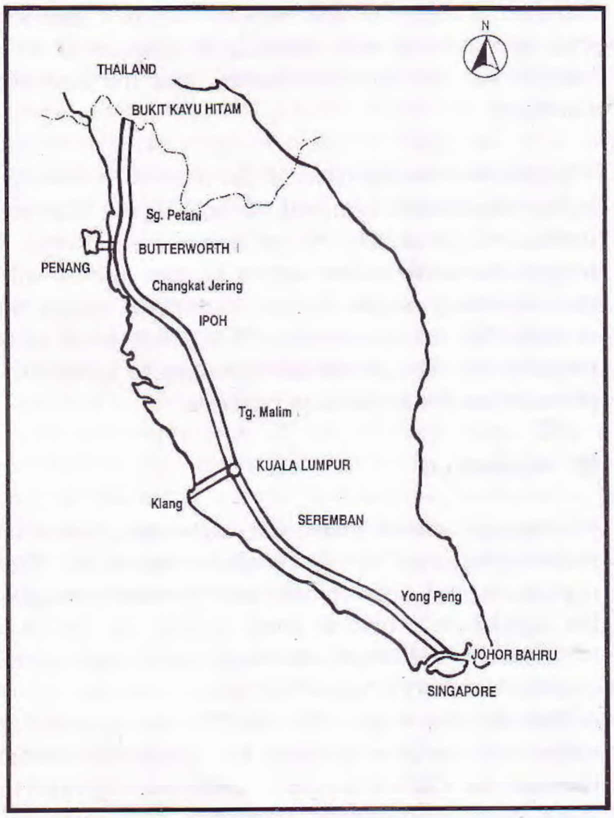


Fig. 5: North-South Expressway

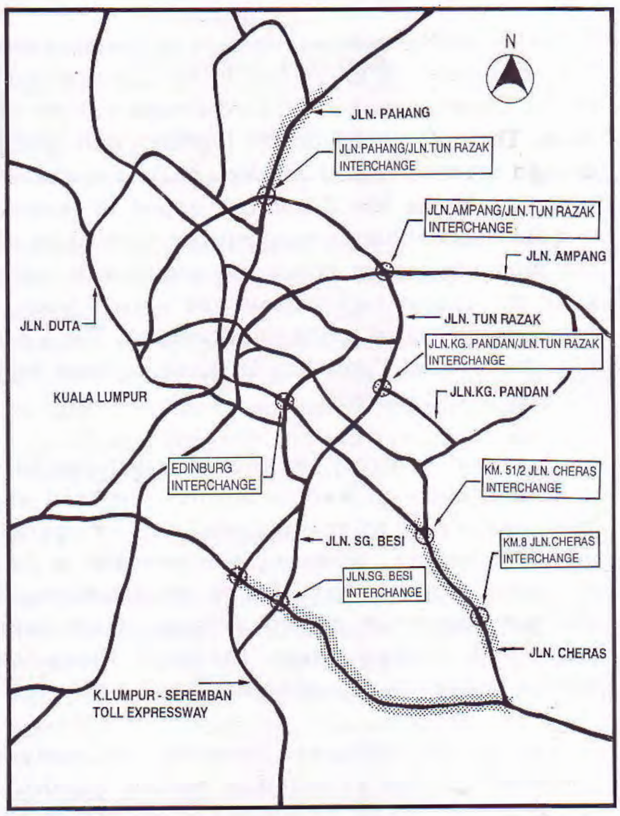


Fig. 6: Upgrading of Cheras Road, Pahang Road and Certain Intersections in Kuala

indicated in Table 2.2. These features shall be elaborated in the following sections.

■ Highway Planning

As opposed to individual projects, highway planning is a broad base function. It can and should only be carried out by a Government agency at the macro level. Projects which are suitable for privatisation are identified from the planned road network through feasibility evaluation on the financial viability using toll as the main source of revenue. Highway planning is never a feature in the concession agreement.

■ Engineering Design

Site investigation and detailed engineering design are the responsibilities of the concession company. The projects privatised so far fall into three categories in which the engineering design of the highway are at different stages of completion.

In the first category, the detailed design had been completed and the project was ready for tendering in the conventional way. In the invitation to submit proposal, the detailed design and works specifications were offered to the interested company/consortium who was given the option to either adopt the design and specifications in total or to offer alternatives which should not be inferior to the offered design and specifications in terms of functional requirement, geometrics and performance standards. The North-South Expressway belongs to this category.

In the second category, preliminary engineering design had been prepared in the feasibility study carried out by the Government but detailed design was yet to be done. The preliminary design together with specified design standards and works specifications were included in the bid document issued to interested company/consortium, who should on submission of its bid proposal declare either full compliance with, or state the extent to which it had varied from, the requirements stated in the bid document. The Kepong Interchange And Upgrading Of Kuching Road project belongs to this category.

In the third category, neither detailed design nor preliminary design were available. The road alignment, usually of an existing road due for upgrading owing to capacity inadequacy, was presented in the bid document together with design specifications. The company/consortium making proposal would have to prepare the detailed design. The North Klang Straits Bypass belongs to this category.

In any of the category, however, the company/consortium is not expected to include the detailed design at the time of submission of proposal, but it is required to enclose the general highway layout and a statement of undertaking to comply fully with the design requirement. The cost of survey, investigations and design by Professional Engineer will be borne by the company. The company is given the liberty to incorporate the most innovative and cost effective technologies into the design, which will reflect the competitiveness of its proposal.

In the implementation stage, the detailed designs must be approved by the Government (through its technical agency) before construction can commence. The design and approval can be made progressively as construction progresses.

■ Construction

As opposed to the conventional arrangement where supervision of construction works is carried out by the Engineer (Government's own engineer or consulting engineer), supervision on site in a BOT agreement is carried out by engineers appointed by the concession company. The responsibility for quality assurance lies entirely with the concession company. Nonetheless, the Government reserves the right to have access to site for inspection of works and for examining test records in order to satisfy itself that concession agreement requirements are complied with. Notwithstanding any checking by the Government, it is to the interest of the concession company to ensure quality in the construction as the company itself will be responsible for the maintenance over a long period in the concession. Poor quality in construction will increase the cost of repair and maintenance.

Before the highway and related facilities can be put into operation, a joint acceptance inspection will be carried out by the Government and the concession company.

The period of completion of the physical works is left to the concession company to decide, but this period forms the initial part of the concession period. The longer the construction period is, the shorter will be the remaining period for toll collection, hence lesser revenue for the concession. Thus there is an in-built pressure on the concession company to complete the physical works as soon as possible.

■ Operation

For non-privatised roads and highways, operation is entirely handled by Government agencies. Traffic regulation and enforcement are governed mainly by the legislation known as Road Traffic Act. In the case of privatised highways, the Road Traffic Act and other related legislations still apply except for toll collection, for which the right to demand toll from road users has been given to the concession company through the Federal Roads (Private Management) Act 1984. Law enforcement, however, still remains the responsibility of the Police and other Government agencies such as the Road Transport Department.

Traffic management, emergency communication and towing services, rest and service facilities are operated by the company.

■ Maintenance

Routine maintenance, periodic maintenance and major repairs are the entire responsibility of the concession company. For the earlier projects like the North Klang Straits Bypass and the Kepong Interchange And Upgrading Of Kuching Road, only brief specifications of maintenance standard had been written in the concession agreement. A lot of details were left to be sorted out during the maintenance period. Experience has shown that it is necessary to document detailed requirements in order to avoid confusion and disputes. As such, in the North-South Expressway concession agreement, it was stipulated that a maintenance manual would be prepared for all aspects of maintenance.

To ensure compliance with the maintenance requirements by the concession company, a **maintenance bond** is provided to the Government by the company. (e.g. RM 20 million for North-South Expressway and RM 0.3 million for Kepong Interchange) The amount of the bond shall always be maintained (topped up) every time there is a demand on the bond by the Government against failure on the part of the company to maintain.

■ Toll

Tolling is a rather sensitive issue socially. Experience has shown that for tolling to be acceptable to the road users, there must first of all be an alternative toll-free route. Secondly, the tolled highway, be it a new highway or an upgrade of an existing one, must have geometric standard and level of service higher than those of any competing road. And thirdly, the toll must be at a level generally affordable by the users. All these three aspects are controlled by the Government at various stages. By policy, alternative toll-free route would have been identified at the planning stage before the project is assigned for privatisation. Design standard and level of service of the toll highway would have been specified at the bidding stage. The toll amount or toll rate is either fixed by the Government before bidding or agreed between the Government and the company during negotiation. In any case, affordability of the road users predominates over other financial considera- tions.

Two tolling systems are in use in Malaysian highways, namely, the **OPEN TOLL SYSTEM** and the **CLOSED TOLL SYSTEM**. As a general rule, open toll system is used in urban and semi-urban highways where access is not fully controlled, whereas closed toll system is used only in long interurban expressway where access is fully controlled. The North Klang Straits Bypass, the Kepong Interchange And Kuching Road, and Upgrading Of Cheras Road, Pahang Road And Certain Intersections In Kuala Lumpur projects use the open toll system. Only the North-South Expressway uses the closed toll system.

For the earlier two projects, namely the North Klang Straits Bypass and the Kepong Interchange And Kuching Road, the toll amount is fixed for each project and shall remain constant throughout the whole concession period. The concession companies for these two projects do not have difficulty in accepting the constant toll amount as the concession periods are relatively short and the risk against inflation is low. For later projects, however, escalation of toll tied in with the consumer price index is incorporated into the concession agreement so as to hedge the project against inflation over relatively long concession periods (in the order of three decades). Except for adjustments due to inflation, the toll is fixed, and the company has no right to vary the toll. On the other hand, the Government may suppress the toll, but such suppression will have to be accompanied by appropriate compensation to the company.

For the purpose of toll collection, vehicles are grouped into six classes as shown in the following table:–

CLASS	DESCRIPTION
0	vehicle with 2 axles and 2 wheels (motor cycle)
1	vehicle with 2 axles and 3 or 4 wheels but excluding a taxi
2	vehicle with 2 axles and 6 wheels but excluding a bus
3	vehicle with 3 or more axles
4	taxi
5	bus

For social reasons, Class 0 vehicles (motor cycles) are exempted from toll; Class 4 vehicle (taxi) pays only half the toll of Class 1 vehicle (passenger car); while Class 5 vehicle (bus) pays about three quarters of that of Class 1 vehicle. The purpose of this is to lighten the burden on the lower income group. Tolls for Class 2 and Class 3 are about 1.5 and 2 times of that of Class 1 respectively.

■ Ancillary Facilities

For the North-South Expressway which is a long inter-urban expressway, the concession company is obliged to provide along the expressway ancillary facilities like rest and service areas, lay-by, advertising hoardings and other amenities which may be operated on the expressway. The right to enter into licensing, franchise or other contractual arrangements to operate the ancillary facilities and to collect payments therefrom is vested with the company. Thus this

provides a subsidiary source of revenue for the company. The design and construction of the facilities are subject to the approval of the Government.

Financing

The main feature that differentiates privatised highway projects from the conventional or turnkey projects is in the financing of the project. The concept of privatisation calls for the private concession company, instead of the Government, to undertake the project financing from its own source. From the point of view of the concession company, there are three basic factors which need to be examined in order to decide on the commercial feasibility of a project. Firstly, the project must be financially **viable**. The return on equity must be high enough to attract share holders of the company to invest. Secondly, the equity to be injected into the project must be at a level **affordable** by the company. (It is important that the company's financial capability be carefully evaluated at the bid evaluation stage.) Thirdly, the project's financial proposal must be " **bankable** ", i.e. to be able to obtain financing from banks and financial institutions. Generally, the equity loan ratio would not exceed 1:4 in normal circumstances.

Profit (high return on equity) is the objective. The company, however, bears the risk just like it would in any other commercial venture. Financial parameters such as actual traffic volume and construction costs may vary substantially from those estimated for the pre-project financial simulation. Such variation may be to or against the advantage of the concession company. In the North Klang Straits Bypass and the Kepong Interchange And Kuching Road projects, this concept is fully applied. These concession companies have so far not faced any particular problem in this respect as the project viabilities are high and the concession periods short, making the risk to the companies low.

For big projects, however, estimation of construction costs, projection of traffic volume (and hence revenue) and other financial parameters become more prone to inaccuracy because of the long concession period. As such the risk in the project viability becomes high. If cost estimates and traffic projections are prudently made, big projects are quite often not viable, and this makes such projects not 'privatisable' unless some modifications are made to the concept. Therefore, in order to reduce the risk borne by the company, the Government in many cases found it necessary to provide certain form of support to the company. Such support came in the form such as subordinated loan, traffic volume supplement loan or adverse foreign exchange rate/interest rate movement supplement loan. These supports are meant to assist the company in their cash flow. The loan supplements are stand-by facilities which becomes available only at certain predetermined trigger level.

Traffic Projection

Like all predictions, traffic projection is subject to various uncertainties which will affect its accuracies. Confidence in its accuracy becomes lower as the period of projection gets longer. Traffic volume is totally beyond the control of the Government or the company. It is also the most important parameter which affects the viability of the project. Except where stand-by supplement loan facility against adverse shortfall in traffic projection is given by the Government as mentioned in Section 6 above, the concession company is entirely responsible for the accuracy of its own traffic projection which it uses for viability assessment. Some preliminary review on the accuracy of projections is given in Section 7 below.

7. Performance

It is appropriate now to review the performance of some of the project which have been implemented so far, although none of them has reached the end of the concession period.

North Klang Straits Bypass

During the construction phase, the company did not report any cost overrun in providing the physical facilities. The Bypass has performed satisfactorily since its opening in December 1984, except that the roadway is reaching its capacity and requires widening. A comparison of projected and actual traffic volume is shown in Fig.7.

Kepong Interchange And Kuching Road, Kuala Lumpur

This project has also performed satisfactorily since its opening in 1987, except for occasional congestion at the toll plaza during festive seasons. The company did

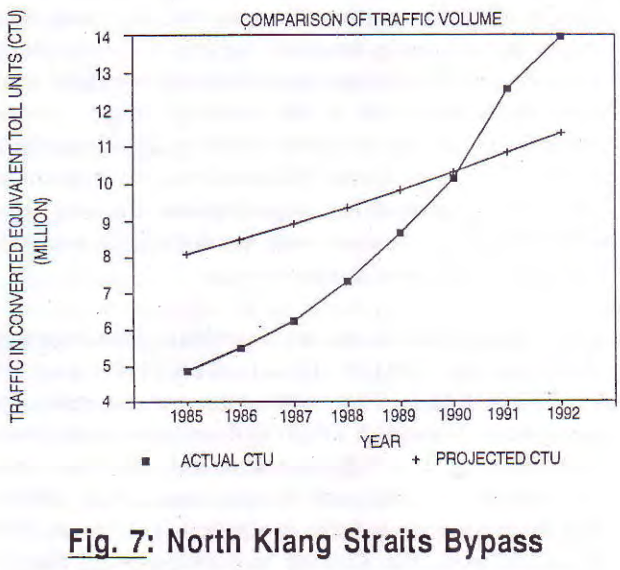
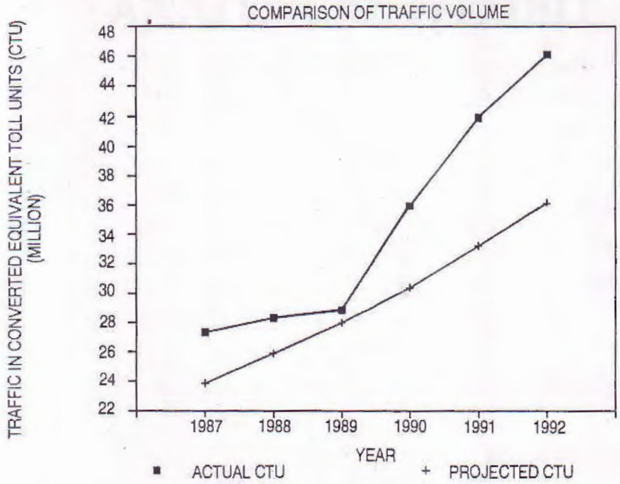
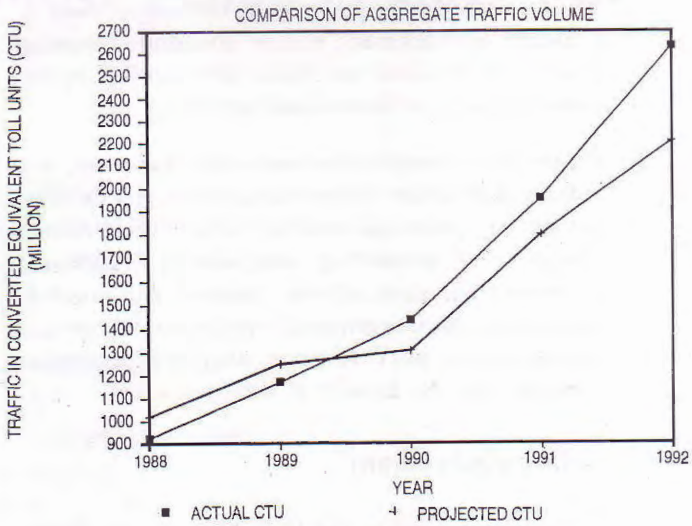


Fig. 7: North Klang Straits Bypass



Note : Toll unit is the toll payable by one passenger car. Predetermined toll unit equivalents are assigned to the other classes of vehicles.

Fig. 8: Kepong Interchange/Kuching Road



Note : Toll unit is the toll payable by one passenger car. Predetermined toll unit equivalents are assigned to the other classes of vehicles.

Fig. 9: North-South Expressway

not report any cost overrun problem, but it suffered heavier loan repayment owing to severe adverse exchange rate movement during the earlier years of the project. Such loss, however, has been more than compensated by the higher than projected traffic volume. Fig.8 shows the comparison between the actual and projected traffic volume.

■ North-South Expressway

To date, this project is partially completed and open to traffic. The rest of the expressway is under construction and is scheduled for completion in early 1994. The company has announced severe cost overrun, from original budget of RM 3446 million to RM 5987 million. While the overrun is serious, the company is optimistic that the project is still viable basing on the very favourable higher than projected overall traffic volume carried by the completed sections. Fig.9 shows the situation of the aggregated traffic volumes of all the completed sections up to now. Over the whole length of the Expressway, the high volume sections are cross-subsidising the lesser viable sections. In terms of service, generally the completed sections have provided very good service to the users.

8. Future Projects

The performance of privatised highway projects has so far been very encouraging. More projects are now in the pipeline for privatisation, and they are at various stages of implementation. In time, Malaysia will gain even more experience in this mode of infrastructure financing.

9. Conclusion

Privatisation of highway projects has so far proven to be advantageous in the following ways:–

- ☐ Against the ever growing demand on Government resources for development, privatisation has enabled the Government to implement major and financially viable highway projects earlier than by way of normal budget allocation. This has in turn enabled Government fund to be channelled to other socially desirable but financially non-viable projects. Just for the projects discussed in this paper, such additional resource is in the order of billions of ringgit.

- ☐ Privatisation has relieved the Government of some operational and maintenance burden. For example, prior to the privatisation of the North-South Expressway, the Malaysian Highway Authority had built and operated 324 km (in sections) of the expressway. The yearly operating cost was approximately RM 17 million on the average. The staff working on those sections numbered about 600, with a yearly emolument cost of about RM 5 million. On privatisation, the staff and the operating function and responsibility have been transferred to the company. The former employees of the Malaysian Highway Authority continue their employment in a private company where they enjoy higher salaries and other fringe benefits.

- ☐ Road users have generally enjoyed an improved standard of service.

- ☐ Minimising cost and maximising profit is the basic objective of the concession company. This has given much incentive to the concession company

to incorporate innovative ideas, particularly in construction technique. e.g. a technique used in building embankment across abandoned mining ponds has resulted in about 50% saving in the construction cost on embanking filling.

- ☐ Provision of services to road users, however, is a natural monopoly. Privatisation of highway does not by its nature necessarily fulfil Government's objective of promoting competition, improving efficiency and productivity. There is still much to be done on tbe Government's part to supervise and regulate the performance of the concession company for the benefit of the road users.

10. Acknowledgement

The author is grateful to the Hon. Minister of Works, Malaysia, for permitting this paper to be published.

ANALYTICAL FLEXIBLE PAVEMENT DESIGN IN THAILAND

by

SUKREE DHEERAGOOL
Deputy Director-General
Department of Highways
Thailand

TEERACHARTI RUENKRAIRERGSA
Director
Road Research and Development Center
Department of Highways
Thailand

1. INTRODUCTION

Flexible pavements consist of a series of layers constructed on the subgrade or prepared layers. Generally, flexible pavement in Thailand is composed of asphaltic concrete surface overlying layers of compacted base course, subbase course, selected materials layer, and subgrade. The surface course must carry the high stresses induced by traffic without unacceptable deformation. The major structural layer in the pavement is the base course whose purpose is to distribute traffic loads so that the stresses and strains developed by them in th subgrade and subbase are within the capacity of the materials in these layers. The subbase is also a load distributing layer but is of weaker material than the base course. In addition, it provides a suitable working platform on which to construct the upper layers of the pavement. The load distributing capacity of individual layers is a function of both their thickness and the mechanical stiffness of materials in them.

In most flexible pavement structures the stiffness of each layer is greater than that of the layer below, and smaller than that of the layer above. Layers consisting of some types of cementitious base materials may be exceptions to this general rule.

Methods for the design of flexible pavements may be classified in two groups, namely empirical method and analytical or theoretical method. Analytical method is a term generally used in Europe, while it is called a mechanistic method in the United States in a similar sense. The empirical method is based on past experience and may include laboratory or field tests of the subgrade and pavement materials. In some methods these tests are primarily for identification or classification of the materials while in others they give quantitative information about their mechanical properties. Some of the empirical methods are the CBR method (PORTER, 1938; 1942; 1949), CORPS OF ENGINEERS (1961), TRRL Road Note 29 (TRANSPORT AND ROAD RESEARCH LABORATORY, 1970), NATIONAL CRUSHED STONE ASSOCIATION (1970), and AASHO (1972).

Empirical design methods for pavement are satisfactory so long as the materials and conditions of loading for which they developed do not change. However, traffic volumes and, more particularly, traffic loadings have tended to increase quite drastically in recent years. Furthermore, the introduction of some new materials may be inhibited if it is not possible to assess with any precision the thicknesses and conditions under which they should be use. The extension of empirical design methods into regions of new loading and new materials can be achieved only by carrying out expensive and time-consuming full-scale pavement experiments. The analytical design methods do not suffer from these drawbacks. The very heavy loading on many modern roads as well as the variability of the materials used in the pavement structure, has produced a design problem both for new roads and the partial or complete reconstruction of the existing ones for which present empirical design methods might be less reliable.

Thailand Department of Highways employed the empirical design method for more than two decades. As a consequence of the aforementioned reasons it is proposed to change a design method to an analytical approach. It is the purpose of this paper to introduce the analytical design method just initiated by the Department recently.

2. BRIEF HISTORY OF ANALYTICAL PAVEMENT DESIGN

Before discussing the analytical pavement design in more detail, it is benificial to consider, briefly, the historical development of the method, which emerged relatively recently as a discipline in its own right.

Although some early analytical work was published in 1926 by WESTERGAARD (1926) relating to concrete pavement, little further development took place until 1943 when BURMISTER (1943) published a paper entitled **"The Theory of Stresses and Displacements in Layered Systems and Application to the Design of Airport Runways"** which indicated developing interest in analyzing the pavement structures by an elastic theory.

In the elastic theory relating the stresses and deformations of the road pavement it is assumed that the pavement consists of a number of layers all infinite in the horizontal direction and the layer overlying the subgrade (asphalt surface) is considered to be of infinite thickness. The layers are all assumed to be homogeneous and elastic. However different properties are assigned to the uppermost layer by different researchers. Some, such as WESTERGAARD (1926), and ODEMARK (1949) treated it as an elastic plate, while others, particularly BURMISTER (1943; 1945) and HANK and SCRIVNER (1948) treated it as an elastic layer. The difference between the two approaches is that an elastic plate is subjected to bending deformation but suffers no vertical deformation due to direct stress, whereas is an elastic layer all the stresses are considered and no restrictions are placed on the deflections. The elastic layer is thus a more general treatment of the problem than the elastic plate.

Although BURMISTER (1943; 1945) developed the elastic theory for the three-layer system, he did not give the equations for deducing the stresses or compute the stresses and deformations likely to interest highway engineers. In 1948, FOX (1948) published a paper dealing with the distribution of stresses in a two-layer system, and in 1951 ACUM and FOX (1951) published a paper giving the values of the interfacial stresses in a three-layer system on the vertical axis through the center of the tire contact area. Both papers were developed on the basis of the works of BURMISTER (1943; 1945). The contract area was assumed to be circular and subjected to a uniformly distributed pressure. Poisson's ratio was taken as 0.50 throughout the system, the interfaces were expressed in tabular form for various thicknesses and modular ratio. Further values of stresses in a three-layer elastic system were computed later form Burmister's works by the Shell Petroleum Company (JONES, 1962).

Ability to analyze pavements for design and performance created the need for material descriptors such as representative modulus values and Poisson's ratio. At this point a major problem was encountered, particularly in relation to flexible pavement since asphalt is a viscoelastic material with temperature dependent properties. In 1954, VAN DER POEL (1954) laid the foundation for a usable method for determining the stiffness of asphalt with a monograph for asphalt stiffness. HEUKELOM and KLOMP (1964) based a method for calculating the stiffness of a low void content asphalt mix in the VAN DER POEL Monograph. However, knowledge of the stresses and strains within a pavement are of no use for design purposes unless further data relating the performance of material to the stress condition is available.

In 1955, HVEEM (1955) attributed cracking in pavements to the repeated flexing of the asphalt, or in other words, to fatigue. Thus the need for research into the fatigue behavior of asphalt was established and significant contributions to knowledge in these area were made by PELL (1962), and MONISMITH et at (1970).

During this period interest in an analytical approach to pavements had been growing in the United States. This interest led to the organization of the International Conference of the Structural Design of Asphalt Pavements at the University of Michigan in 1962 which was conceived partially as a forum for discussing of the results of the AASHO Road Test. This conference represents the birth of the analytical approach to pavement design, gathering papers worldwide, and providing the first international meeting of the people concerned specifically with analytical design of pavements. A number of interesting papers were presented at this conference, which hich laid the foundation for the development of the analytical method. Some of them are papers by PEATTIE (1962 a), DORMON (1962), and BURMISTER (1962). Of particular value was a paper entitled "The Application of Elastic Theory to Flexible Pavement" by WHIFFIN and LISTER (1962) which provided much evidence to validate the use of elastic analysis as a tool for designing the flexible pavements.

Having started in 1962, International Conferences on the Structural Design of Asphalt Pavements have been held subsequently at five yearly intervals in 1967, 1972, 1977, 1982 and 1987, chronicle the development of analytical pavement design has been recorded. The 1967 and 1972 conferences contains many papers on the characterization of paving materials, necessary as input data for both analysis and design. During this period, pavement analysis was undertaken by the use of tables such as those produced by JONES (1962) and ACUM and FOX (1951), or by the use of charts, as produced by PEATTIE (1962 b). However, the rapid development of computer technology offered improved computational power and led to the production of programs for analyzing pavements. The well known BISTRO program was introduced in 1968 by PEUTZ et al (1968). The BISTRO program was modified later to be a BISAR program by Shell Oil Company; and this program was employed in preparing the Shell Pavement Design Manual (CLAESSEN et al, 1977; DE JONG et al 1973; SHELL INTERNATIONAL PETROLEUM COMPANY LIMITED, 1978). Other programs are many such as CHEVRON, DAMA, CIRCLY, ELMOD, FEPAVE, PSAD, PSAD2A, etc.

In 1987 the International Society for Asphalt Pavemehts (ISAP) was formed by the resolution of the Executive Committee of the Sixth International Conference on the Structural Design of Asphalt Pavements. One specific activity of the Society is to ensure the continuity of a series of international conferences devoted to the structural design, construction, maintenance and management of asphalt pavements.

Thus the scene was set, material data analysis tools were available, and as a result the 1977 International Conference was devoted mainly to paper presenting complete design methods, or subsystems for treating parts of the design problems. During 1982 and 1987 Conferences, a number of papers on various aspects of analytical pavement design were published.

Before passing on, note should be made of the considerable contributions to flexible pavement design technology by the Shell Oil Company and Chevron Research Company who, through their research centers, have provided much of the basic research upon which the analytical design methods have been based.

3. PAVEMENT DESIGN METHODS ADOPTED BY THAILAND DEPARTMENT OF HIGHWAYS

Thailand Departments of Highways initially employed the empirical CBR design method (PORTER, 1949) in an early stage of highway development. The CBR design chart is shown in Fig. 1. The design method was changed to the one of the Seventh Edition of the MS-1 of the Asphalt Institute later. Today the Eight Edition of the MS-1 published in 1970 has been used for many years. The soil parameter used in thickness design is a CBR value. Performing the CBR test is easy and fast, and this makes the design methods of the Asphalt Institute acceptable generally for the flexible pavement design in Thailand. So far The Asphalt Institute Method has been used by-Thailand Department of Highway for about 20 years.

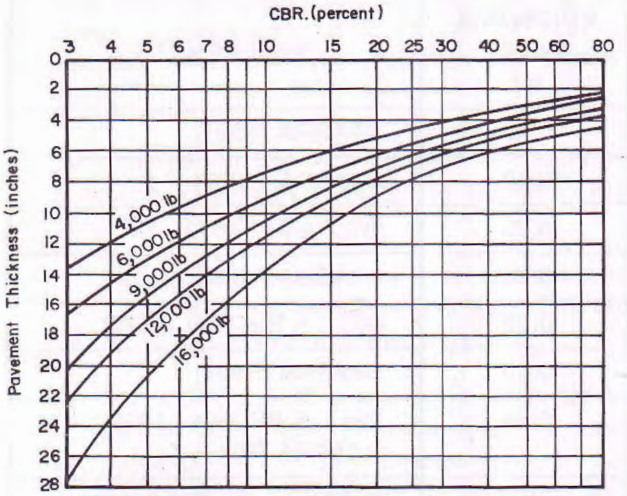


Fig. 1: CBR Design Curves for Highways (CORPS OF ENGINEERS, 1961)

During the past time, traffic load and volume increased considerably, and presently there are a number of overloaded trucks passing through the road in the country. In addition, there exists the problems that the local available materials have inferior properties compared to the standard values suggested by the Asphalt Institute. Many roads, especially the low volume roads, are forced to employ the substandard materials for the pavement structure. On the basis of the stated handicaps, it seems inevitable to introduce the concept of analytical procedure to make an analysis and a design of the appropriate pavement structure suitable to the local traffic loading and available materials.

Since 1988 the Thailand Department of Highways has tried to translate the originally developed PSAD2APC computer program with intensions to initiate an analytical pavement analysis and design to the Thailand Department of Highway. It is hoped appropriate pavement structures corresponding to roads carrying very heavy traffic loads, or roads constructed with the available local materials could be confidently designed with this modified computer program.

4. INTRODUCTION OF ANALYTICAL DESIGN TO THAILAND DEPARTMENT OF HIGHWAYS

■ PSAD2A Computer Program

This is a computer program specially developed for a dual wheel loading. It is derived from a PSAD computer program developed by KASIANCHUK (1968). The PSAD computer program is a stress-modulus iteration in the Chevron Five-Layer Program. It is used to solve the state of stress at any point within the pavement structure section under the action of a single circular loaded area of uniform contact pressure. The PSAD2A computer program was developed later by the UNIVERSITY OF CALIFORNIA (1970) to calculate the load response under the dual wheel. The PSAD2A computer program calculates stresses and strains at seven horizontal locations underneath the loaded area at three depth in each layer. Fig. 2 illustrates the locations of a five-layer system where stresses and strain are calculated.

■ PSAD2A-PC Computer Program

For the sake of convenience in operation at the Materials and Research Division of the Thailand Department of Highways, the original PSAD2A computer program was translated into a PSAD2APC

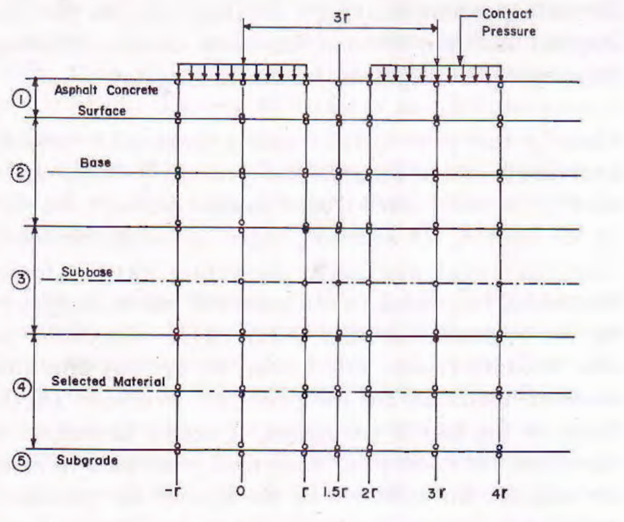


Fig. 2: Position of the Calculation under the Dual Wheel of the PSAD2A Programme (KASIANCHUK, 1968)

computer program which was written in BASIC language for use with personal micro-computer. In additional the graphic program was also incorporated into the presently developed PSAD2APC computer program. The associated graphic program tends to enable the main program to plot the stress, strain and deflection with depth across the section at all specified locations underneath the loaded area.

■ Typical Pavement Structure and Pavement Material Parameter

Generally the typical pavement structure of the Thailand Department of Highway consists of five

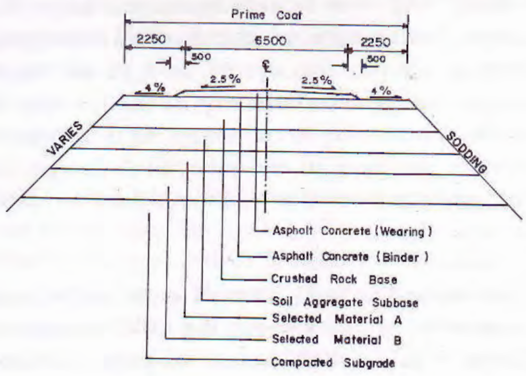


Fig. 3: Typical Pavement Cross-Section of the Thailand Highway

layers of various pavements materials as follows.

- □ Asphalt surface
- □ Crushed rock base/soil-cement base
- □ Soil aggregate base /soil-cement subbase
- □ Soil aggregate selected materials
- □ Subgrade

However, the soil aggregate selected materials layer might be omitted where the bearing value of the subgrade is high and the traffic volume is low. The typical pavement cross section designed by the Eighth Edition of the MS-1 of the Asphalt Institute is shown in Fig. 3.

Table 1: Appropriate Values of Elastic Modulus (E) and Poisson's Ratio (μ) of the Pavement Materials

PAVEMENT MATERIALS	ELASTIC MODULUS (E) lb/in^2	POISSON'S RATIO (μ)	REFERENCES
Asphalt Concrete	150 000	0.40	NAASRA (1987)
Crushed Rock Base	60 000	0.40	NAASRA (1987)
Cement Modified Crushed Rock Base	1 000 000	0.25	WILLIAMS (1972)
Uncracked Soil-Cement Base	750 000	0.25	NAASRA (1987)
Cracked Soil-Cement Base	200 000	0.25	PELL & BROWN (1972)
Soil Aggregate Subbase	30 000	0.40	NAASRA (1987)
Soil-Cement Subbase	200 000	0.40	PELL & BROWN (1972) NAASRA (1987)
Soil-Aggregate Selected Materials	15 000 (1 500 CBR)	0.40	KLOMP & DORMON (1964)
Subgrade	1 500 CBR	0.45	KLOMP & DORMON (1964)

The pavement structure obtained by the Asphalt Institute Method will be analyzed for the allowable number of load repetitions and fatigue life by the PSAD2APC computer program in order that the trends of conclusions are expected to be drawn on the analytical basis. For the sake of employing the PSAD2APC computer program in the analysis, the elastic parameters for each layer must be assigned as the input data. Their values are tabulated in Table 1. The values of the modulus of elasticity (E) and the Poisson's ratio (%) were compromised from a number of literature (PELL and BROWN, 1972; WILLIAMS, 1972; NAASRA, 1987).

■ Proposed Design Criteria

Two modes of failure caused by traffic was illustrated in Fig. 4. The designer tries to avoid both modes of failure within the design life. The concept of design life is particularly important for pavements, since they do not fail suddenly but gradually deteriorate over a period. This is essentially a fatigue phenomenon, in the sense that the deterioration, which is caused by the stresses and strains in the structure, resulted from both the magnitude and the number of load repetitions the pavement experiences which induced these stresses and strains.

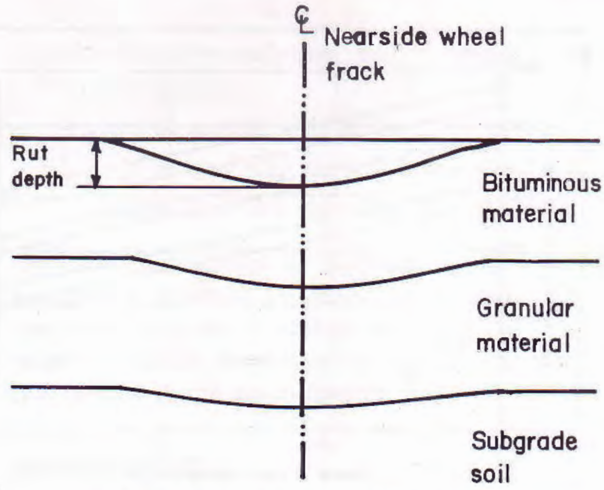
Cracking of the asphalt layer arises from repeated tensile strain, the maximum values of which occurs at the bottom of the layer as shown in Fig. 4b. The crack once initiated, propagates upwards causing gradual weakening of the structure.

The development of the rut, shown in Fig. 4a arises from the accumulation of permanent strain throughout the structure. So far as the asphalt layer is concerned, this can be minimized by a suitable mix design procedure based on the use of a performance test and by good compaction of all layers. If the vertical strain in the subgrade is kept below a certain level, past experience has shown that excessive rutting will not occur, unless poor mix design of inadequate compaction are involved (BROWN and BRUNTON, 1988).

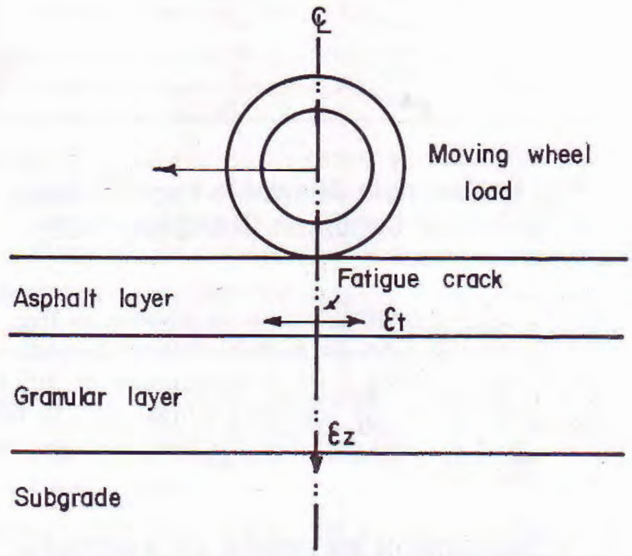
Two design criteria will be used for an analytical approach of pavement design as shown in Fig. 4b. They are:

- ☐ Maximum horizontal radial tensile strain on the underside of the asphlat bound layer. This controls the cracking of the asphalt layer.
- ☐ Maximum vertical compressive strain on the surface of the subgrade. This controls the permanent deformation of the subgrade layer, in turn, to permanent deformation of the pavement surface.

In both cases, the maximum allowable values depend on the number of load applications expected in the design life of the subgrade. The relationship between maximum allowable subgrade compressive strain and the number of load applications is shown in Fig. 5. (BROWN and BRUNTON, 1984; 1988), and that for the maximum allowable asphalt tensile strain and the



(a) Permanent deformation



(b) Faligue cracking and critical strains

Fig. 4: Failure Modes and Critical Strains in Asphalt Pavement

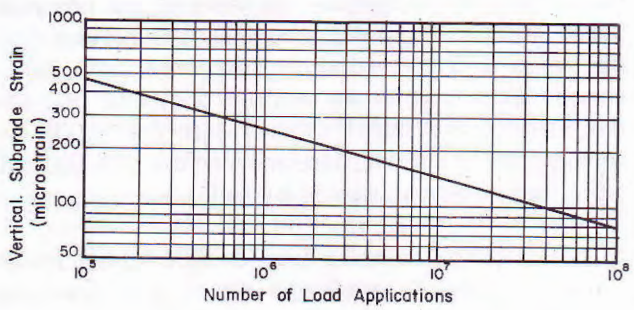


Fig. 5: Maximum Allowable Subgrade Strain to Critical Conditions (BROWN & BRUNTON, 1984)

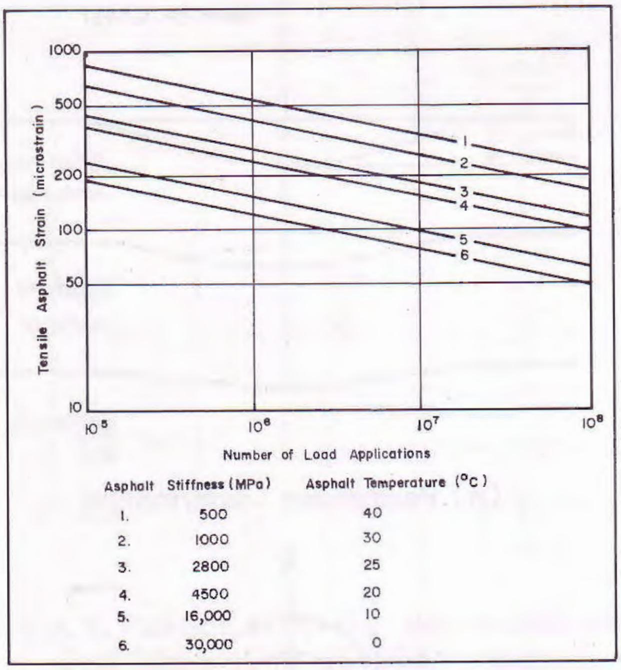


Fig. 6: Maximum Allowable Asphalt Strain to Critical Condition (NAASRA, 1987)

number of load applications is shown in Fig. 6 (NAASRA, 1987) As the asphalt stiffness depends on temperature, so line 2 for a temperature of 30° C, corresponding to the asphalt stiffness of 150 000 lb/in^2, will be selected for further analysis for Thailand condition.

5. COMPARISON BETWEEN AN EMPIRICAL AND AN ANALYTICAL PAVEMENT DESIGN METHODS

The presently used thickness design manual (MS-1) of the Asphalt Institute is the eighth edition which was developed in 1970 on the basis of the observed performance from the AASHO Road Test. The thickness-to-traffic relationships were empirically based. This empirical method tends to use the statistical procedures to correlate the thickness combination of surface, base and subbase with the road performance which affected by traffic.

In developing the thickness design relationships for the eighth edition of the MS-1, it is generally recognized that dependence on the AASHO Road Test data could result in significant limitations. Some of the major limitations are as follows:

- There was a single subgrade soil at the AASHO Road Test and no variations in compaction or other conditions.
- Except for a few special sections, the base course was a crushed limestone aggregate and the subbase was a natural gravel or soil aggregate. This is similar to the ones used in the typical pavement structures of the Thailand Department of Highways as aforementioned.
- There was no direct provision made for different environmental conditions.
- In the design chart, the miximum gross vehicle weight is 27 tonnes, and the maximum single axle load limit is 10.2 tonnes. These values do not correspond to the heavy trucks on some highways that carry the very heavy traffic with a high potential or overloading.

The analytical design of the asphalt pavement has been developed since 1962 as a consequence of the First International Conference on the Structural Design of Asphalt Pavements in the United States. The analytical design method cannot be easily described in the manner that the previous empirical methods were described, because it is much more complex and consists of a number of subsystems controlling the safety of a particular position or material in the layout. It requires assumptions about the number of load applications and the magnitude of the loads, because these are needed to calculate the allowable stresses or strains in various materials composing the asphalt pavement. The materials in the layer are characterized in terms of the elastic parameters, namely, the modulus of elasticity and Poisson's ratio, as well as their allowable stress or strain values.

The analytical design method is related to the design of structures since the composition and thicknesses of the layers are selected so that the stresses, strains and deflections produced by design traffic loading do not exceed the capabilities of any of the materials in the pavement layers. The proportions of the pavement structure are adjusted until an acceptable design results in which all the critical factors are within the permissible limits. In the analytical design the artificial materials such as cemented base and modified asphalt concrete surface that posseses relatively high strength and stability could be put in the pavement structure, and the theoretical analysis on their performance could be made on the basis of their elastic properties. In addition, the analysis could be made for a particular wheel load. So, the method could be applicable for the very heavy wheel load as well as for the very heavy traffic volume road.

LISTER et al (1982) stated that empirical design methods were generally developed on the basis of limited load repetitions, mostly lower than 10 MSA. However, it was found that the pavement empirically designed for 10 MSA could carry the traffic repetitions to 30 MSA. But for the very heavy traffic motorway the number of the load repetitions will be typically more than 80 MSA, with the value as high as 160 MSA on some busiest sections. It will be seen that the designed of a heavy duty pavement like this by an empirical method will be very risky because the

thickness and load applications relationship beyond 10 MSA seems to be unreliable. It is generally suggested that a pavement structures having a capability to sustain the load repetitions of 100-200 MSA is designed by the use of an analytical pavement design method which will be discussed later.

6. DESIGN PROCESS OF THE ASPHALT ROADS FOR MOTORWAY OF THE DEPARTMENT OF HIGHWAYS

In designing the road for the Department of Highways, asphalt pavement for motorways with a high potential of overloading will be designed in two stages. In the first stage the thicknesses of the pavement layers will be obtained by the empirical design method of the Asphalt Institute as aforementioned. Then the obtained pavement structure will be analysed for stress, strain and deflection under both the standard wheel load and the very heavy wheel load. The CHEVRON type computer program is adopted for this analysis. In the analysis the quality of the pavement materials might be changed in order to satisfy the results of the adopted criteria. The pavement materials could be changed from conventional crushed rock base or soil aggregate subbase to cement modified crushed rock base or soil-cement subbase, respectively, depending on the potential failure occurring under the pavement due to the load repetitions. The subgrade soil might be stabilized, if necessary, to prevent the rut formation due to fatigue. In addition, the thicknesses of the layer could be adjusted to increase the structural safety and longer service life. The pavement analysis will be repeated until the appropriate pavement structure for carrying the potential traffic repetitions during the design period is obtained. This pavement structure is generally adopted for the analytical design, and it should be adequately safe for very high traffic repetitions, as well as very heavy trucks.

7. CONCLUSIONS

- ☐ There are two methods of pavement design, empirical and analytical. Empirical design is based on the past experience while analytical design employs the elastic moduli of the pavement materials as design parameters.
- ☐ Thailand Department of Highways adopted the empirical design of the Asphalt Institute Manual Series 1 for about 20 years.
- ☐ Today there are many institutions trying to develop an analytical method for both analysis and design of flexible pavement.
- ☐ Some of the important analytical methods are the shell Method, The Asphalt Institute Method, Chevron Method, NAASRA Method, and the University of Nottingham Method.
- ☐ Advantages of the analytical method are many, and some of them are,
  - it could be applied with inferior local material,
  - it could be used with the very heavy wheel load,
  - it could be used with some complicated structure.
- ☐ Thailand Department of Highways initiates the analytical method by using the PSAD2APC computer program to analyse different pavement structures for the purpose of an appropriate design conforming to the environments in Thailand.

8 REFERENCES

AASHO (1972), AASHO Interim Guide for Design of Pavement Structures, American Association of State Highway Officials, Washington, D.C., U.S.A.

ACUM, W.E.A. and FOX, L. (1951), Computation of Load Stresses in a Three-Layer Elastic System, Geotechnique, Vol. 2, No. 4, pp. 293-300.

BROWN, S.F. and PELL, P.S. (1972), A Fundamental Structural Design Procedure for Flexible Pavements, Proc. Third International Conference on the Structural Design of Asphalt Pavements, Vol. 1, University of Michigan, pp. 369-409.

BROWN, S.F. and BRUNTON, J.M. (1984), Improvements to Pavement Subgrade Criterion, J.ASCE, Transportation Engineering Vol. 110, No. 6, November, pp. 551-567.

BROWN, S.F. and Brunton, J.M. (1988), An Introduction to the Analytical Design of Bituminous Pavement (3rd Edition, University of Nottingham, Department of Civil Engineering, United Kingdom.

BURMISTER, D.M. (1943), The Theory of Stresses and Displacements in Layered System and Application to the Design of Airport Runways, Proc. Highway Research Board, National Research Council, Washington, D.C., U.S.A.

BURMISTER. D.M. (1945), The General Theory of Stresses and Displacements in Layered System, III, Journal Applied Physics, Vol. 16, No. 5, pp. 290-302.

BURMISTER, D.M. (1962), Application of Layered System Concepts and Principles to Interpretations and Evaluations of Asphalt Pavement Performances and to Design and Construction, Proc. First International Conference on Structural Design of Asphalt Pavement, University of Michigan, U.S.A., pp. 218-233.

CORPS OF ENGINEERS (1961), Revised Method of Thickness Design for Flexible Highway Pavements at Military Installation, Waterways Experiment Station, Technical Report 3-582, August, Mississippi, U.S.A.

DE JONG, D.L., PEUTZ M.G.F. and DORSWAGEN, A.R. (1973), Computer Program BISAR. Layer System under Normal and Tangential Surface Loads, Koninklijke 1 Shell-Laboratorium, Amsterdam, External Report, AMSR. 006.73.

DORMON, G.M. (1962), The Extension to Practice of a Fundamental Procedure for the Design of Flexible Pavements, Proc. First International Conference on the Structural Design of Asphalt Pavements, University of Michigan, pp. 551-522.

DORMON, G.M. (1962), and METCALF, C.T. (1965), Design Curves for Flexible Pavements Based on Layered System Theory, Highway Research Record 71, Highway Research Board, National Research Council, Washington, D.C., U.S.A.

FOX, L. (1948), Computation of Traffic Stresses in a Simple Road Structure, Road Research Technical Paper, No. 9, H.M.S.O., London, United Kingdom.

HANK, R.J. and SCRIVNER, F.H. (1948), Some Numerical Solutions of Stresses in Two and Three-Layered System, Highway Research Boards Proceedings, Washington, D.C., U.S.A.

HEUKELOM, W. and KLOMP, A.J.G. (1964), Road Design and Dynamic Loading, Proc. Association of Asphalt Paving Technologists, Vol. 33, pp. 94-123.

HOGG, A.H.H. (1938), Equilibrium of a Thin Plate, Symmetrically Loaded, Resting on an Elastic Foundation of Infinite Depth, Philosophy Magazine. Vol. 25, pp. 576-582.

HVEEM, F.N. (1955), Pavement Deflections and Fatigue Failure, Highway Research Board Bulletin 114, Highway Research Board, National Research Council, Washington, D.C., U.S.A., pp. 43-87.

JONES, A. (1962), Tables of Stresses in Three-Layer Elastic System, Highway Research Board bulletin 342, Highway Research Board, National Research Council, Washington, D.C., U.S.A., pp. 176-214.

KASIANCHUK, D.A. (1968), Fatigue Considerations in the Design of Asphalt Concrete Pavements, Unpuublished Ph.D. Dissertation, Department of Civil Engineering, University of California, Berkeley; U.S.A.

KLOMP, A.J.G. and DORMON, G.M. (1964), Stress Distribution and Dynamic Testing in Relation to Road Design, Proc, Second Conference of the Australian Road Research Board, Melbourne, Australia.

LISTER, N.W., and GODDARD, R.T.N. (1982), A Design for Pavement to Carry Very Heavy Traffic, Proc. Fifth International Conference on the Structural Design of Asphalt Pavements Vol. 1, The University of Michigan, U.S.A., pp. 84-91.

MONISMITH, C.L., SECOR, K.W. and BLACKMER, E.W. (1970), Asphalt Mixture Behavior in Repeated Flexure, Proc. Association of Asphalt Paving Technologists, Vol. 39, pp. 207-236.

NATIONAL ASSOCIATION OF AUSTRALIAN STATE ROAD AUTHORITIES-NAASRA (1987), Pavement Design-A Guide to the Structural Design of Road Pavement, National Associations of Australian State Road Authorities, NSW, Australia.

NATIONAL CRUSHED STONE ASSOCIATION (1972), Flexible Pavement Design Guide for Highways, National Crushed Stone Association Publication, Washington, D.C., U.S.A.

ODEMARK, N. (1949), Investigations as to the Elastic Properties of Soil and Design of Pavements According to the Theory of Elasticity, Statens Vaginat. Stockholm Medd., Vol. 77.

PEATTIE, K.R. (1962a), A Fundamental Approach to the Design of Flexible Pavements, Ibid., pp. 487-494.

PEATTIE, K.R. (1962b), Stress and Strain Factors for Three-Layer Elastic System, Highway Research Board Bulletin 342, Highway Research Board, National Research Council, Washington, D.C., U.S.A.

PELL, P.S. (1962), Fatigue Characteristics of Bitumen and Bituminous Mixes, Proc. First International Conference on Structural Design of Asphalt Pavements, University of Michigan, pp. 310-323.

PEUTE, M.G.F., VAN KEMPEN, H.P.M. and JONES, A. (1968), Layered System Under Normal Surface Loads, Highway Research Record 228, Highway Research Board, National Research Council, Washington, D.C., U.S.A.

PORTER, O.J. (1938), The Preparation of Subgrades, Proc. Highway Research Board, Vol. 18, Part 2, pp. 324.

PORTER, O.J. (1942), Foundations for Flexible Pavements, Proc. Highway Research Board. Vol. 22, p. 100.

PORTER, O.J. (1949), Development of the Original Method for Highway Design, Proc, ASCE, Vol. 75, p. 11.

ROAD RESEARCH LABORATORY (1970), A Guide to the Structural Design of Pavements for New Roads, Road Note 29 (3rd Edition), HMSO, London, United Kingdom.

SHELL INTERNATIONAL PETROLEUM COMPANY LTD., (1978), Shell Pavement Design Manual-Asphalt Pavement and overlays for Road Traffic, London, United Kingdom.

THE ASPHALT INSTITUTE (1970), Thickness Design-Full Depth Asphalt Pavement Structure for Highway and Street, Manual Series No. 1 (MS-1), Eighth Edition, the Asphalt Institute, College Park, Maryland, U.S.A.

UNIVERSITY OF CALIFORNIA (1970), Asphalt Behavior in Repeated Flexure, Report TE 70-5, University of California Berkeley, U.S.A.

VAN DER POEL, C. (1954) A General System Describing the Visco-Elastic Properties of Bitumens and Its Relation to Routine Test Data, Journal of Applied Chemistry, Vol. 4, pp. 221-236.

WESTERGAARD, H.M. (1962), Stresses in Concrete Pavements Computed by Theoretical Analysis, Public Roads, Vol. 7, No. 2. April, pp. 25-35. WHIFFIN, A.C. and LISTER, N.W. (1962), The Application of Elastic Theory to Flexible Pavements, Proc. First International Conference on the Structural Design of Asphalt Pavements, University of Michigan, pp. 611-634.

YODER, E.J. (1959), Principles of Pavement Design, John Wiley & Sons, Inc., New York, U.S.A.

YODER, E.J. and WITCZAK, M.W. (1975), Principles of Pavement Design Second Edition, John Wiley & Sons, Inc., New York, U.S.A.

USE OF CONCRETE BLOCKS AS PAVEMENT STRUCTURE

by

RICARDO S. BASA
Chief Engineer, Civil Works Division
DCCD Engineering Corporation, Philippines

BIENVENIDO V. GALANG
Soils & Material Engineer
DCCD Engineering Corporation, Philippines

1. INTRODUCTION

The concrete paving block was one of the type of pavement specified in the projects of the Third Philippines-IBRD Ports Project which includes Cebu and Iloilo in Visayas, and Cagayan de Oro and Zamboanga in Mindanao. This type of pavement was specified for the open storage area and marshalling yard of the ports.

In the Philippines, the use of the concrete paving blocks, although not new, is not yet commonly specified in construction. Therefore, the objective of this paper is to document the experience gathered in the construction of this type of pavement in one of the Third Philippines-IBRD Ports Project, the Zamboanga Port where DCCD Engineering and Design Management and Development Corporation was involved in the Construction Supervision as Local Consultants to the Project Management Office of the Ministry of Public Works and Highways and the Philippine Ports Authority as the implementing agency.

The concrete blocks proposed to be used in the project were originally hexagonal with dimension of 100 mm on each side and 100 mm thick. But during implementation, approval was given to use rectangular blocks of 120 mm x 240 mm thick instead. The rectangular blocks were arranged in a herringbone pattern.

Zamboanga Port traffic.

Zamboanga Port traffic.

The paving blocks were non-reinforced and designed to carry heavy loads and envisioned to behave like a flexible pavement since they were constructed in the reclaimed areas with hydraulic fill of about 7 to 9 meters deep.

In the project, the areas to be paved with concrete blocks was increased from a total area of 20,650 sq.m. to 31,900 sq.m. during construction. Beside marshalling yard and open storage areas, the adjacent service roads and the loading dock of the CFS (Container Freight Shed) were also paved with concrete blocks instead of asphalt concrete. This was the result of the change order given that all asphalt pavement were to be paved with Portland cement concrete (PCC) pavement. However, in the said particular areas, concrete paving blocks was selected in-lieu of the PCC pavement.

2. DESIGN

The design of the pavement structure of the third ports project using concrete paving blocks was based on the load, forklift FD-250 (25 tons capacity Forklift) and the sub-grade support value determined from CBR (California Bearing Ratio) test. The CBR design method for the design of a flexible airport pavement was adapted to determine the pavement structure

thickness. At the port of Zamboanga, the subgrade CBR value obtained from the soil investigation was 15% and the value was adopted in the design. Based on these data, the pavement structure comprised of the following elements:

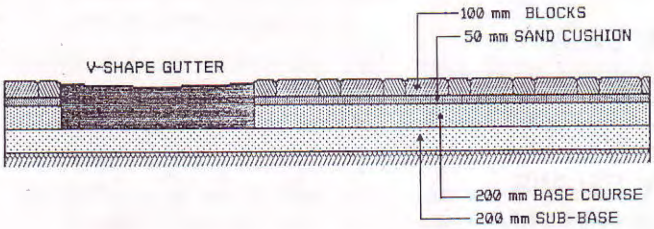


Fig. 1

■ Surface Course – 100 mm Concrete Blocks

The original design were hexagonal blocks with dimension of 100 mm on each side, but approval was given for the use of rectangular blocks 120 x 240 x 100 mm. The blocks were casted with concrete of 4,000 psi compressive strength and aggregates with a maximum size of 10 mm. Chamfer was provided on the wearing surface of the concrete block and specified that the surface area bounded by the chamfer should not be less than 75% of the total plan area of the block. All sides of the blocks were perpendicular to its normal axis and the allowable discrepancy in dimension was limited to 3 mm.

■ Laying Course

The laying course consists of sand bedding 50 mm thick after compaction. The sand was specified to be clean, free from deleterious substances and clay lumps. The sand had 100% passing on sieve No. 4 with not more than 35% by weight passing on sieve No. 50. The fine fraction passing on sieve No. 100 was not more than 10% and that passing on sieve No. 200 not exceeding 3%.

■ Base Course

The base course was 200 mm thick, comprises of well-graded sand and gravel crusher run with plasticity index not exceeding 6. The aggregate maximum size was 50 mm (2") and the fraction of the aggregates retained on sieve No. 4 had a minimum crushing value of 60%. The base course was compacted to 100% of the maximum dry density as determined in accordance with AASHTO T-180d.

■ Sub-base

The sub-base consisted of 200 mm of granular materials with a minimum CBR of 25%. It was compacted to a minimum 98% of the maximum dry density in accordance with AASHTO T-180d.

■ Edge Restraint

The edge restraining block is of prime importance to prevent the concrete blocks from displacing outward. Any movement will widen the gap between the blocks thus ruining the interlock. The edge restraint must be of heavy unyielding block. In the figure shown, the edge restraint used in the project were V-shaped gutter and adjoining PCC pavement. Other typical edge restraints that can be used in relation with the direction of crossfall slope for surface drainage can also be seen in the figure.

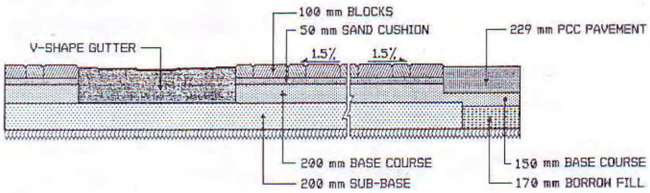


Fig. 2: Concrete Blocks Abutting V-Shape Gutter & PCC Pavement

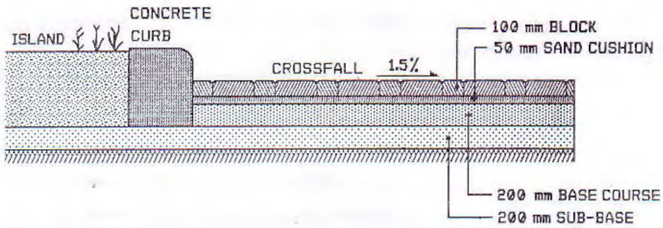


Fig. 3: Concrete Blocks Abutting Concrete Raised Curb

3. MANUFACTURE OF CONCRETE BLOCKS

In the three (3) ports, Cebu, Iloilo and Cagayan de Oro, the concrete blocks were manufactured using machinery imported from Japan and Germany, while in Zamboanga Port, fabrication was done semi-manually utilizing concrete hollow blocks (CHB) vibrating table for the compaction of concrete. Steel moulds used were manufactured in the machine shop. The chamfer was provided at the mould's base so that the smooth bottom face of the precasted block became the exposed surface of the paving course.

The concrete was mixed to a very low consistency with a slump of 0-25 mm using one bagger mixer and discharged to a mixing board. The concrete was then manually scooped into the moulds and placed in a pallet. The pallet contained 6 moulds when place on the CHB machine for vibration. Vibration normally takes 20 seconds. The excess concrete was struck-off after thorough vibration. The moulded blocks were brought to the curing table and placed upside down. Moulds were removed after 45 minutes to 1 hour when

the concrete had initially set. Surface imperfection, voids or cavity due to entrapped air were then filled and retouched by masons. The casted blocks were water cured for 24 hours in the casting bed before transfer to stockpile area. Stockpiles of blocks were continuously water cured until the required compressive strength is attained.

Random sampling was conducted on every production of not more than 20,000 blocks. Ten (10) samples were taken in every sampling. The mean compressive strength and standard deviation of the 10 samples selected were determined. Concrete blocks were accepted in lots upon compliance with the dimensional and characteristic strength requirements. However, for purposes of production control the manufacturer also conducted his own test for each day of production. Daily rate of production was about 5,000 pieces for a sixteen (16) hours working time with 200 moulds.

4. LAYING THE CONCRETE BLOCKS

Base Course

The prepared base course were clean of all loose stones or gravel and other foreign materials, and it be checked tbat it followed the lines and grades shown in the plans and specifications.

Laying Course

The 50 mm thick laying course was spread uniformly over the prepared based with screeding guides. The sand was laid loose, thicker than 50 mm. (at 60 mm to 70 mm) to give allowance for settlement when compacted. It shall be dry and friable when laid. Stepping on the laid and screeded sand shall be prevented.

Surface Course

The laying of concrete blocks was guided with string lines set in both directions transverse and longitudinal to the alignment of the concrete blocks. The string lines were set to control the alignment, elevation and crossfall slope. Laying of the concrete blocks started at the lowest portion of the area to be paved and shall progress in one direction only. Starting at lowest area prevented the sand laying course from eroding when it rains. It also improved interlock due to the resultant weight of the blocks which pulls toward its adjacent installed blocks for tighter fitting. A wood mallet was utilized to adjust the block to its correct position and level.

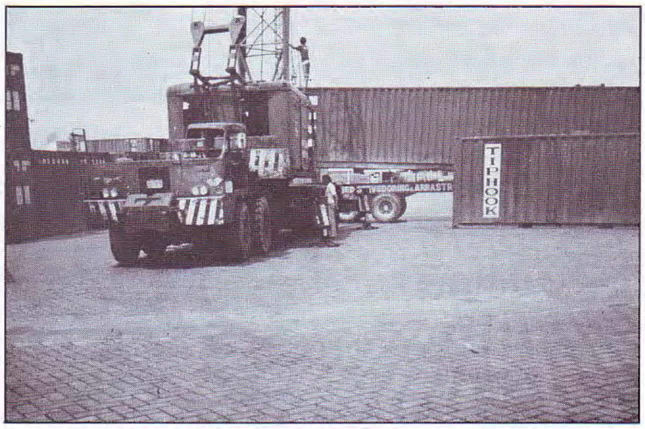
The concrete blocks were laid by 3 or 4 skilled blocks layers and the speed of laying depends on the supply of the blocks to the block layers. Each block layer must have at least 2 support for the supply of blocks and may be more if stockpiles of blocks are far from the area being paved. The average rate of laying is 400 to 500 blocks per hour. The maximum gap allowable between block is 6 mm since dimensional tolerance on each block was 3 mm. However, it was noted that interlock improves with smaller gaps. As such machine blocks were superior in quality because of the consistency in manufacturing and dimensions.

The gaps between laid blocks were filled with fine sand and vibrated with plate compactor to consolidate. The sand must be clean and conform to the grading requirements in the specifications. At least three (3) passes of the vibratory plate compactor were needed for initial compaction.

The different level of installed blocks was corrected by the initial vibratory compaction. It also sets the blocks firmly and uniformly on the sand cushion. Bigger rollers, 8 to 10 tons (vibratory preferred) follows for final compaction.

The edge blocks which are fraction of the standard concrete blocks unit were casted in-situ instead of cutting the pre-casted blocks into correct shape and fitting it exactly in place. In laying the concrete blocks, an allowance for the concrete blocks shall be set about 10 mm. higher than the adjacent PCC pavement or any other edge restrain. This is due to the sand laying course was not yet compacted when the blocks were laid. A laborious mistake was experienced in the actual block laying at the Zamboanga Port when the blocks were installed exactly in the same level with the adjoining PCC pavement and V-shaped gutter. This resulted in depression of the laid blocks lower than the PCC Pavement and V-shaped gutter when subjected to traffic load. Correction has to be made by removing and re-installing the already laid blocks, giving allowance for settlement. The correction work has to be done in a wider area to comply with the required crossfall and straightness.

After thorough compaction the excess sand filler is removed and the completed area was cleaned and open to traffic.



Port operation using crane for loading/unloading containers, six years after the concrete paving blocks have been installed

5. PERFORMANCE EVALUATION AND CONCLUSION

The concrete blocks pavement along the existing T-head approach and the open storage area has been opened to port operations since September 1985, upon its turn over to Philippine Ports Authority of the completed T-head west portion and its back up areas. Other areas paved with concrete blocks such as the marshalling yard, the south loading dock area of the container freight shed, the adjacent service roads to the marshalling yard and open storage areas have been in-use for more than six (6) years after its installation. Initially, the traffic in these areas were mostly loaded dump trucks, transit mixers and various heavy equipment working in the project. Portion of the marshalling yard was used as stockpile area for the base course materials and uninstalled concrete paying blocks. Observation during that period shows the service performance were satisfactory. There was no virtual failure except the depressions at the transition with PCC pavement and the concrete V-shape gutters which serves as restrains. However, the depressions were attributed to the mistake in installing the concrete blocks, which was the same level with the PCC pavement and V-shape gutters, without having considered the allowance for compaction settlement of the sand laying course. These areas were rectified by re-installing the concrete blocks at 10 mm. higher than the concrete edge restrains. A few isolated blocks were noted to be cracked in the middle and it was suspected that this was due to defective concrete blocks or caused by abrupt use of heavy roller without sufficient initial vibro-compaction with plate compactor.

It was also observed that the interlock improves with smaller gap or no gaps at all between the blocks. Machine made blocks were much better because of the consistency in dimensions whereby laying the blocks with no gaps can be achieved. The concrete blocks behaved as flexible pavement because of the interlock, where load applied on any block is also carried by its neighbouring blocks and to lesser extent by the distant blocks.

The chamfer on the block is important to show the aesthetic appearance of the blocks and protects its edge. It also prevents tripping over protruding blocks that were unevenly installed.

On the drainage aspect, the surface run-off due to heavy downpour drains almost like the ordinary pavement with its proper crossfall. A minimum 1.5% slope proved sufficient. The concrete blocks pavement became almost impermeable when the sand filler in between blocks has fully consolidated. Full consolidation of the sand filler is achieved by adequate vibratory compaction or a few months after the pavement is in-use.

In conclusion, for long term, concrete blocks pavement is more advantageous than ordinary PCC pavement in certain areas such as:

- ☐ in places or areas where heavy loads are expected and where speed of vehicular traffic need not be very fast such as, (aside from port areas) fuel depot, gasoline stations, city streets and rural roads, subdivision depot etc. It can also be designed for lighter traffic in places like parks, school grounds, public plaza, etc. where aesthetic appearance is more of vital importance.
- ☐ on reclaimed areas where large settlement is expected or in areas where poor subsurface condition exists. In this case, concrete blocks paving will be far more economical because of its easy and inexpensive repairs.
- ☐ on areas where frequent repair of underground utilities is inevitable.

Other advantages of the paving blocks compared to PCC or AC pavement are:

- ☐ cost of construction is cheaper than PCC or AC pavement
- ☐ construction is labour intensive
- ☐ repair of failed sections is easy to remedy
- ☐ when used in heavily populated areas, vehicles are forced to travel at moderate speed
- ☐ laying of underground utilities does not destroy the pavement
- ☐ pavement life is longer than a PCC or AC pavement
- ☐ very low maintenance cost.

And one of its advantages that may be worth mentioning is that there is no big construction plant needed in the construction of such pavement and for its maintenance.

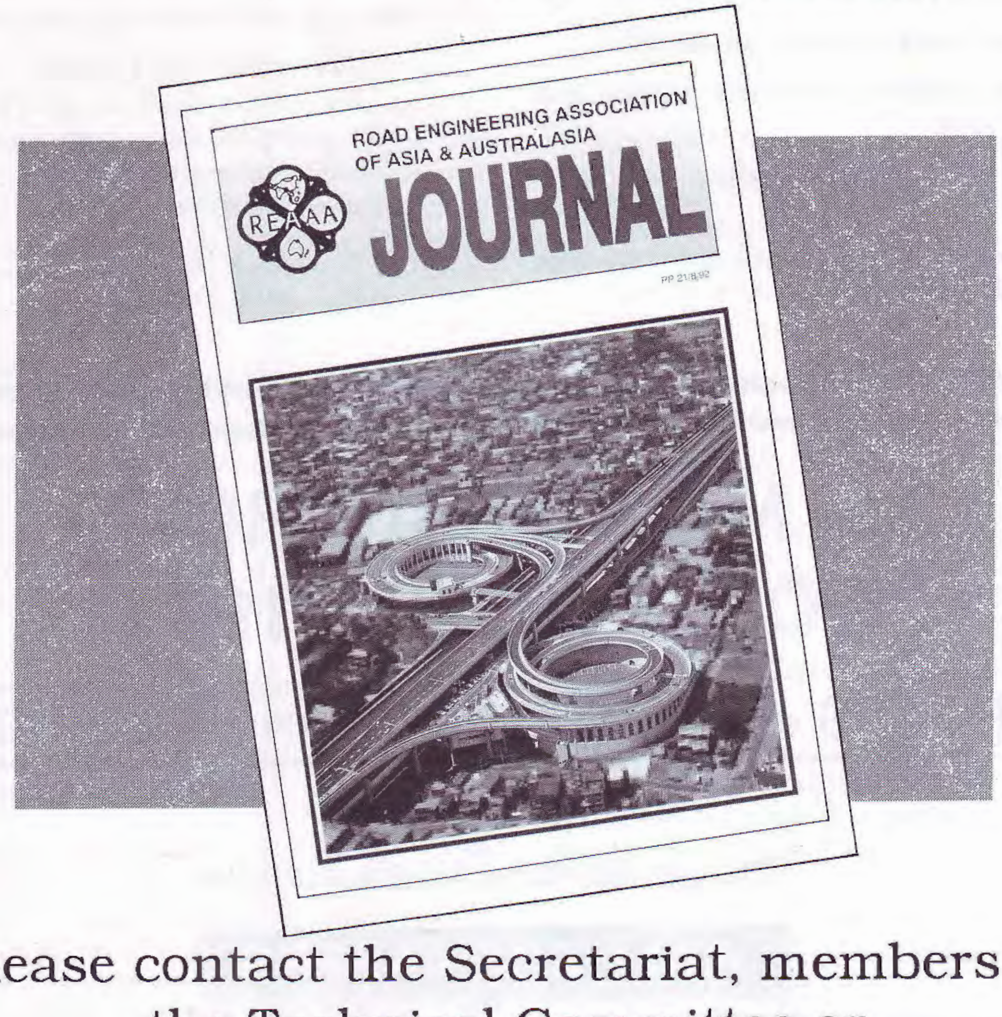
Note:

The above paper was published in the July 1992 issue of Philippine Architectural and Engineering & Construction Record

CALL FOR PAPERS!

Papers are solicited for the
coming issues of the Journal.
The coming themes for the
Journal are:

January 1994 – Traffic Safety
July 1994 – Low Cost Construction
and Maintenance

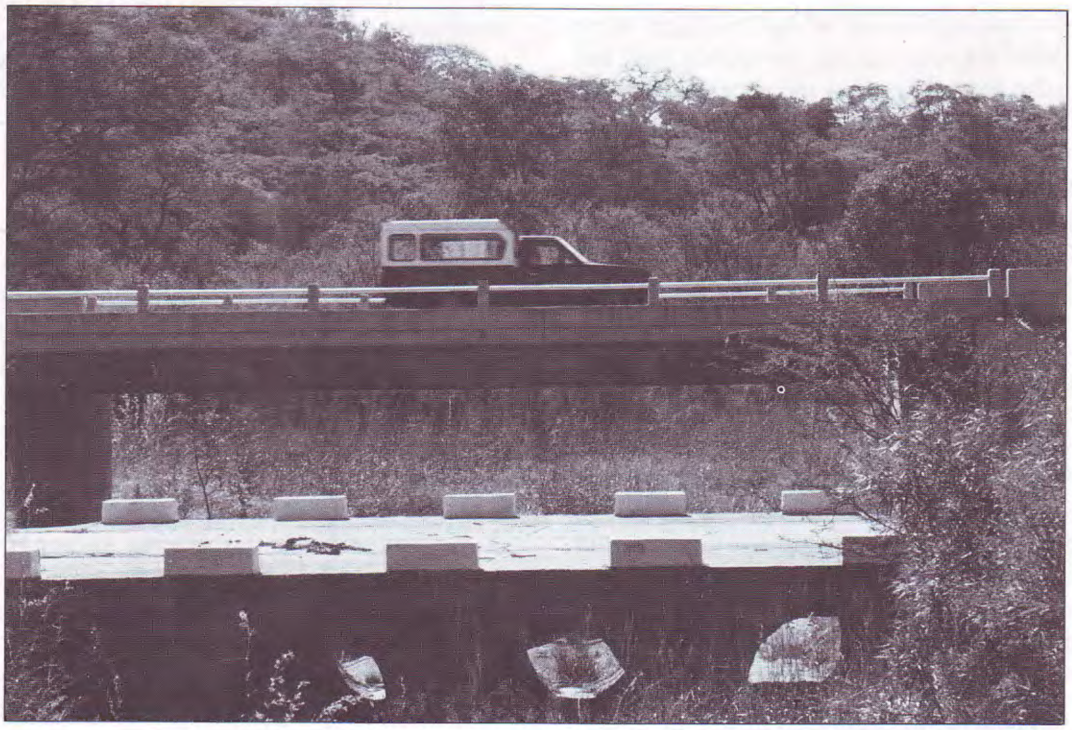


Please contact the Secretariat, members of
the Technical Committee or
Associate Editors in your country.

A DESIGN MANUAL FOR SMALL BRIDGES

by

J D Parry and T E Jones
Overseas Centre,
Transport Research Laboratory, U.K.



ABSTRACT

OVERSEAS ROAD NOTE 9 – "A design manual for small bridges" is the latest in the series Overseas Road Notes published by the Transport Research Laboratory as part of the Aid programme of the British Overseas Development Administration.

The vast majority of structures found on road networks in developing countries are relatively small. The manual focuses on these structures and brings together all the essential requisites for their design from the initial surveys, calculations of waterways, hydraulic measurements, soil bearing pressures to the final structural design.

It is intended for use by bridge engineers but is also aimed at the general civil engineer who has responsibilities other than for bridges. For these engineers particularly, standard designs and tables of dimensions are provided wherever they simplify the design process or save time in detailing and calculation.

This paper illustrates the methodology and summarises the main chapters of the manual.

1. INTRODUCTION

This manual offers highway engineers a comprehensive set of guidelines to assist and simplify the process of designing small bridges and culverts. These structures are an essential part of every road network. They are far more common than large bridges and are simpler to design and construct. For the purposes of the manual, "small bridges" are defined as single or multi span structures with individual spans no more than 12m long, i.e. taking one span to bridge a two-lane highway with shoulders or two spans to bridge a dual carriageway.

The guidelines cover the entire design process, from the planning stage through site investigations and materials analysis, hydraulic design and structural design, to the final preparation of drawings and detailed specifications. There are many textbooks and other technical publications that provide excellent treatments of all these aspects of bridge design: some are listed in the manual as useful reference material for readers wishing to pursue subjects in more detail. These sources, however, are all intended for bridge engineers or students of bridge engineering. The

present manual is meant to be of use in a bridge design office, but it is aimed also at the general civil engineer who is not a bridge specialist but who may nonetheless be required to construct a road that crosses a river or other obstruction. He may be a provincial roads engineer, extending a regional network of feeder roads with permanent bridges, an army engineer or an engineer involved in famine relief distribution, needing rapid but temporary solutions to bridging problems.

Because these non-specialist bridge builders have other professional responsibilities, they rarely have the time or expertise to work out all the necessary bridge design calculations from first principles. For this reason, the manual gives as much guidance as possible in the form of drawings and tables, covering two standards of traffic loading, single or multiple spans, a range of bridge materials – concrete, steel and timber – and a range of in situ soils.

Though the structural design of small bridges can be simplified by the use of stock solutions, the process of hydraulic design cannot be shortened in the same way. The chapters that deal with river hydraulics, hydraulic design and river works contain all the background information and procedures that the bridge designer will need in order to apply the detailed structural tables set out in subsequent chapters, but they assume the knowledge and experience of a qualified engineer as well as the availability of basic facilities for field investigation and soils analysis.

Where there are several possible methods of calculating a variable – for example, allowable bearing pressure or scour depth – the manual presents only the simplest of these methods but includes references to others. When it is thought likely to be helpful, typical calculations are worked out in the appendices to chapters.

2. PLANNING

The first part of the manual is concerned with planning, site investigations, river hydraulics and the hydraulic design of the structure. Planning involves site selection, traffic prediction and design life. It is also necessary at this stage to make an accurate assessment of the available resources, as this has a bearing on the materials to be used and hence the type of structure.

The size and form of the bridge will be decided by the characteristics of the obstacle, whether it is another road, a railway or a river. The essential features are the height of the superstructure and its length and the possibility of employing piers. Also, for a river crossing, account must be taken of the maximum discharge to be accommodated by the main structure, together with relief culverts or occasional overtopping.

Most countries have design loading standards for bridges, but some have not yet determined an appropriate standard for rural roads carrying low volumes of traffic. This manual offers standard design that conform with British Standard loading for 40 tonne gross weight vehicles, and with AASHTO loading for 20 tonne gross weight vehicles. (BSI, 1978 and AASHTO, 1983).

Most two-axle medium commercial vehicles are loaded within the 15 tonne AASHTO limits, but when overloaded they may exceed these limits. HS 20-44 has therefore been used as a conservative standard. The British Standard HA 40 tables are recommended where overloaded three-axle lorries, forestry or quarry vehicles and construction plant are in use.

3. SITE SURVEY

Site selection is often a compromise between the simplest road alignment and the preferred bridge site. For a river crossing, the cheapest bridge site and the one that has the longest potential service life is that which:

- ☐ is on straight reach of the river
- ☐ is beyond the disturbing influence of large tributaries
- ☐ has well defined banks
- ☐ has reasonable straight approach roads
- ☐ permits as square a crossing as possible
- ☐ has good foundation conditions.

The purpose of the site investigation is:

- ☐ to measure the bearing capacity and characteristics of the soils at various depths all over the site and
- ☐ to establish river flow volumes, velocities and levels for normal and flood conditions.

Most river bridge failures result from the aggressive activity of the rivers and not the traffic carried. Attention is given in the manual to understanding the effects of water flow on bridge structures and the effect that bridge works may have on river flow that could result in new scour activity that in turn endangers bridge stability. Emphasis is laid on designing an adequate waterway through the bridge or culvert and protecting the foundations and river banks with rip rap, groynes, piled walls, aprons and curtain walls.

Fig. 1 illustrates the processes of both the planning stage and the design stage in the form of a flow diagram.

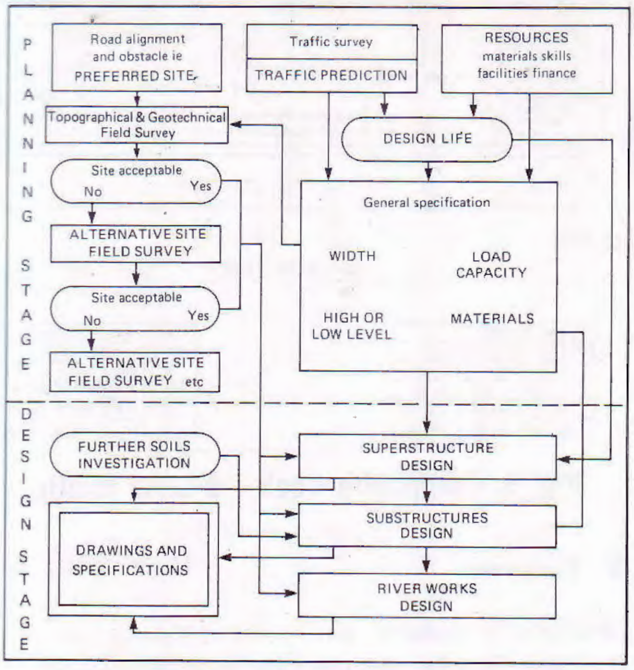


Fig. 1: Flow Diagram of the Design Process

4. SUBSTRUCTURES AND FOUNDATIONS

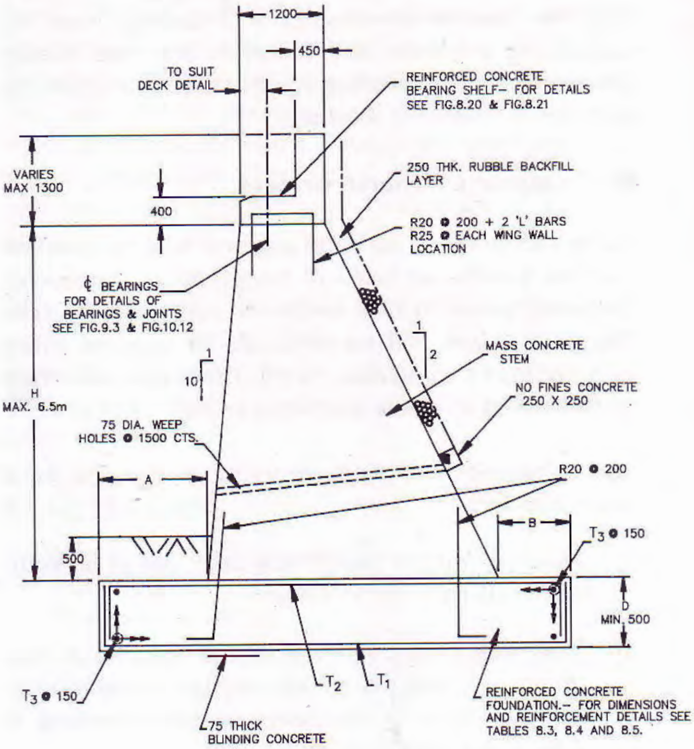
This section deals with the elements of a bridge that supports the dead load of the superstructure, resist the vertical and horizontal live loads on it from vehicles and the elements, retain the approach embankments and provide a smooth transition from road surfaces to the deck running surface. The essential features are:

- foundation slabs, that transmit the weight of the abutments and the superstructure directly to the supporting soil
- front walls with bearing shelves that support the superstructure and usually retain the soil of the embankment
- wing walls or retaining walls.

An important element of this chapter, and those concerning deck design, is the presentation of standard designs and tables of dimensions, whenever these can replace complex individual calculations. This includes a set of standard PC concrete abutment and pier drawings, with tables specifying dimensions, reinforcement etc., for spans up to 12m, heights to 6.5m and a range of soil conditions. The designs are conservative and take into account all the external forces from live and dead loads that substructures are normally expected to sustain.

Structural masonry may be used as a substitute for mass concrete. However, the engineer must be satisfied concerning the strength of the materials used, particularly when submerged in flowing water. A reinforced concrete bearing shelf for use with masonry abutments is also illustrated.

Fig. 2 is an example of the standard drawings that are presented for substructures.



ALL DIMENSIONS IN MILLIMETRES (mm).

Fig. 2: Abutment, Mass Concrete Vertical Section

Concrete abutments and piers may be built to support a timber superstructure that may be replaced at a later date with a more permanent material. In this case the final dead weight, width etc. are used in the abutment design.

5. SUPERSTRUCTURES

Superstructures are divided into three categories:

- reinforced concrete
- composite i.e. reinforced concrete and steel beams
- timber.

Reinforced Concrete Superstructures

This section presents standard designs for concrete slab decks from 4m to 12m spans for one, one and a half, and two lanes of traffic, for both BS-HA and HS20-44 loadings, using mild steel and high yield steel reinforcement.

Bearings

The simplest from of bearing is made by casting the concrete slab onto the abutment bearing shelf, with only a layer of bitumen felt separating the two concrete surfaces. This may be satisfactory for very short spans, up to 6m, but for longer spans there is a risk that thermal movements will damage both the supporting structure and the slab. For this reason simple rubber strip bearing are specified to support the slabs in the standard drawings.

Composite Superstructures

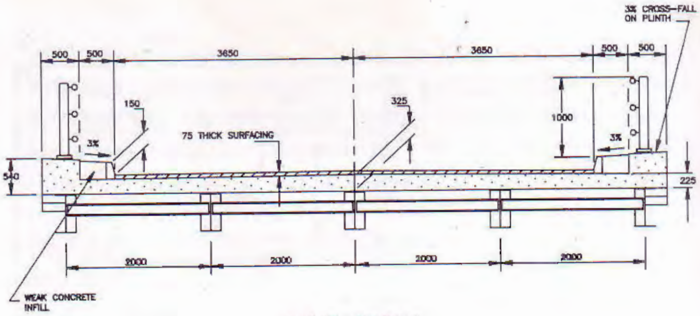
As an alternative to the solid concrete slab, this section presents a series of standard bridge decks constructed from steel beams with a composite concrete deck slab. The main beams and members are of standard rolled carbon steel sections, with the concrete slab reinforcement in either mild steel or high yield steel.

The advantages of steel/concrete composite deck structures are:

- ☐ The deck weight can be less than that of an equivalent all-concrete structure.
- ☐ The off-site prefabrication of the main load carrying elements of the bridge substantially reduced the work necessary on site, resulting in more rapid construction.
- ☐ No temporary supports are required during concreting of the deck slab, as the soffit shutters can be supported directly from the steel beams. This can be a particular advantage at locations with poor ground conditions, steeply sloping terrain, or with a fast flowing stream.
- ☐ Steel is a reliable material which is supplied with guaranteed strength properties, enabling structures of consistent reliability to be produced.

For permanent structures, adequate durability of the steel beams to ensure a service life of 50 years or more can be readily achieved by the use of a cast in situ concrete deck slab. Composite action of the slab and beams is achieved by the use of shear connectors welded to the top flanges of the beams and cast into the concrete.

An example of the standard drawings and tables for composite decks is shown in Fig. 3.



B.S HA LOADING	
SPAN(m)	BEAM SIZE(mm)
6	457 X 191 X 67 UB
8	533 X 210 X 82 UB
10	610 X 229 X 113 UB
12	610 X 229 X 140 UB

AASHTO HS20-44 LOADING	
SPAN(m)	BEAM SIZE(mm)
6	457 X 191 X 67 UB
8	533 X 210 X 82 UB
10	616 X 229 X 101 UB
12	610 X 229 X 140 UB

Fig. 3: Composite Deck – 2-Lane Width

Parapets

Details of a suitable steel parapet system are also provided. Circular sections have been selected for the rails as they are most readily available throughout the world. Provision is made for badly damaged post or rails to unbolted and replaced.

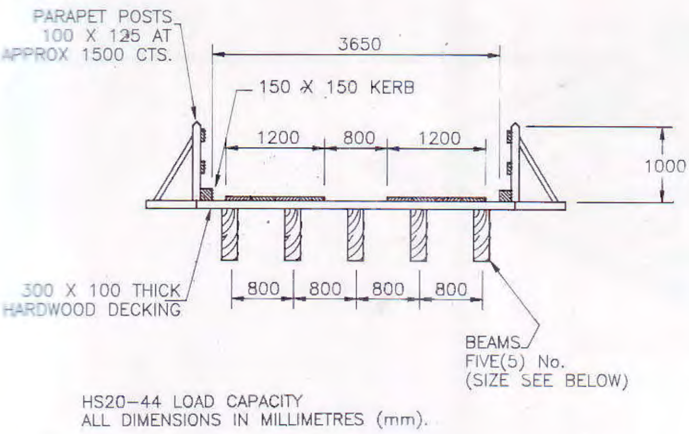
Timber

This section contains designs for single-lane, timber beam decks suitable for AASHTO HS 20-44 loading and spans up to 12m. They are simple to construct and are particularly useful for rapid replacement of superstructures that have been damaged. Timber bridges like the one shown in Fig. 4 are common on rural roads in many countries.

Seasoned logs should be used whenever possible. They should be closely matched and positioned the same way, i.e. with the larger diameter ends all at the same end of the deck such that the decking planks can be fixed in contact with all the logs.

Rectangular timber beams, as shown in section in Figure 5, are also used as the main spanning members for bridges. Construction is easier with such a regular

Fig. 4:



SPAN (m)	BEAM SIZE FOR TIMBER GROUP		
	GROUP A	GROUP B	GROUP C
4	150 X 375	150 X 500	200 X 550
6	150 X 475	200 X 550	200 X 700
8	200 X 500	200 X 650	250 X 750
10	200 X 600	250 X 725	300 X 850
12	200 X 700	250 X 850	300 X 1000

Fig. 5: Timber Beam Bridge – Cross-Section

shape since each member rests on a flat surface and fixing of the decking to the beams is more positive.

Five further chapters in the manual discuss

- ☐ low level water crossings
- ☐ culverts
- ☐ emergency and temporary structures
- ☐ bridge building materials
- ☐ drawings and specifications

It is the purpose of this manual to provide all the necessary procedural guidance, tables, dimensions and material specifications to enable a civil or mechanical engineer with some field experience to prepare appropriate designs. A limited number of copies is available free of charge to government or educational organisations and individuals engaged in or studying bighway engineering. Commercial organisations are asked to pay 10 pound sterling to cover packing and airmail cost.

6. ACKNOWLEDGEMENTS

This manual is based on a draft commissioned from Rendel Palmer and Tritton of London and includes additions and amendments from reviewers in Kenya, Zimbabwe, the Philippines and the United Kingdom. It is published by permission of the Chief Executive of the Transport Research Laboratory and forms part of the programme of work of the Overseas Centre sponsored by the Overseas Development Administration.

7. REFERENCE

AASHTO, 1983. Standard specifications for highway bridges. Washington: American Association of State Highway and Transporta tion Officials.

BSI, 1978. Steel, concrete and composite bridges Part 2. Specification for loads. BS5400:1978 Pt. 2. London: British Standards Institu tion.

PARRY J D, 1991, A design manual for small bridges. Overseas Road Note 9. Crowthorne: Transport and Road Research Laboratory.